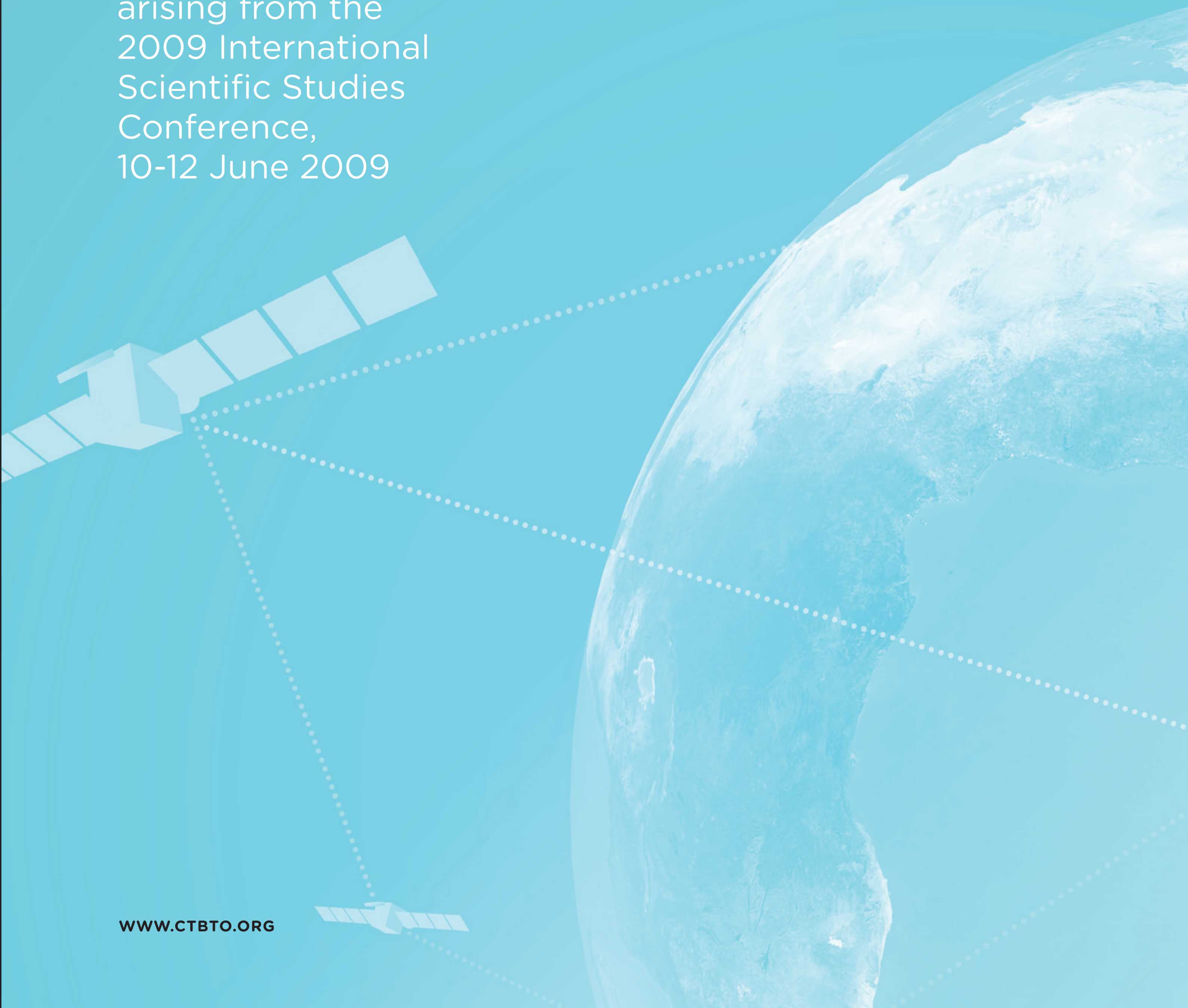
ISS09
INTERNATIONAL
SCIENTIFIC
STUDIES

POSSIBLE PROJECTS FOR THE CTBTO

arising from the
2009 International
Scientific Studies
Conference,
10-12 June 2009



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POSSIBLE PROJECTS FOR THE CTBTO

arising from the 2009 International Scientific Studies Conference, 10-12 June 2009

This report identifies scientific outcomes of the 2009 International Scientific Studies Conference (ISS09) which may be most relevant to the needs of the CTBTO verification regime, and thus suitable for further work fostered by the CTBTO, possibly in connection with a future ISS-type initiative.

SECTION 1 recalls the purpose of ISS09.

SECTION 2 outlines the basis for the preparation of this report.

Specific proposals are described in **SECTION 3**.

APPENDIX I lists the posters presented at the conference.

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Over 200 scientific posters were presented at ISS09.

Foreword

BY TIBOR TÓTH
EXECUTIVE SECRETARY
PREPARATORY COMMISSION FOR THE COMPREHENSIVE NUCLEAR-TEST-BAN TREATY ORGANIZATION

Science is the very essence of our work. Our verification regime depends on it like a tree on the soil that it grows from. The roots of the unique verification regime of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) reach down to the decades long work of the Group of Scientific Experts, who began working on test-ban verification in the 1970s – long before the Treaty's negotiations actually started.

After thousands of man-hours of work by dedicated scientists, this tree has thrived and developed many strong branches devoted to a range of disciplines: geophysics (seismology, meteorology and acoustics), nuclear sciences, computer sciences, system engineering and maintenance, and information and communication technology.

Scientists have helped to make this state-of-the-art system ever more capable – while ensuring that it stays ahead technologically of would-be cheaters. With 281 of the 337 facilities of the International Monitoring System (IMS) already installed, we have absolute confidence that adherence to a comprehensive ban on nuclear explosions can be effectively monitored in the atmosphere, in the oceans and underground.

It is vital for the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) to keep its fingers on the pulse of technological developments. This will not only enable the organization to excel but also has direct ramifications for the future of the CTBT and its organization. One of the preconditions for countries to commit to the Treaty is that they are convinced of the verification regime's effectiveness. I am encouraged by the 153 States that have already demonstrated their full confidence in the regime by ratifying the Treaty. However, for the CTBT to enter into force it must be signed and ratified by all of the 44 so-called Annex 2 States, of which six still need to ratify (China, Egypt, Indonesia, Iran, Israel, and the United States) and three more also need to sign (the Democratic People's Republic of Korea, India and Pakistan).

A fruitful exchange with the scientific community helps us not only to become more effective, but also more efficient. For example, improvements in the automatic detection and location of events using a machine learning approach could reduce the workload of analysts in the International Data Centre (IDC) – and thus decrease the financial pressure on Member States. At the same time, this exchange enables us to attract the best and brightest scientists.

With the verification regime constantly evolving, it is equally important to keep all users of the IMS data and IDC processing results on board. To this end, we have launched the capacity development initiative as part of our efforts to build and enhance the necessary capacities – especially in the developing countries amongst our 182 Member States that have the right to receive CTBTO data – to enable them to participate equally in the implementation of the Treaty and benefit equally from the services of the verification regime.

The capacity development strategy is based on the recognition that building and maintaining the necessary capacity to confront the technical, scientific, political, and legal challenges that face the multilateral non-proliferation and disarmament regime, is of critical importance now and will be in the years to come. There needs to be a greater investment in education – in disarmament education and in education related to the monitoring and verification sciences.

An important milestone in our cooperation with the international scientific community was the International Scientific Studies Conference (ISS) held in Vienna from 10 to 12 June 2009, which brought together 600 participants from 99 countries. Over 200 impressive posters were presented at this conference.

The present report summarizes the scientific outcomes of the ISS which are most relevant to the needs of the verification regime, and thus creates a link between the ISS and the upcoming Science and Technology (S&T2011) Conference in Vienna from 8 to 10 June 2011.

I would like to thank the ISS Coordinators, the CTBTO Points of Contact, and of course the many scientists both inside and outside the CTBTO for their invaluable contributions to the success of the ISS and also encourage them to take an active part in the upcoming S&T2011 Conference.

1. Introduction

The International Scientific Studies Conference held in Vienna on 10-12 June 2009 (referred to hereinafter as ISS09) brought together a wide range of scientists, diplomats and others with expertise in various aspects of the verification regime foreseen by the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The meeting did not issue conclusions, recommendations or resolutions in any formal sense. Instead it was followed by a publication entitled Science for Security: Verifying the Comprehensive Nuclear-Test-Ban Treaty, which was published by the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)[1] in September 2009. In that publication, the "topic coordinators", who were external experts in the relevant scientific fields, summarized their thoughts on the keynote addresses and scientific posters pertinent to their fields.

The approximately 210 posters covered the state of knowledge in numerous topics relevant to CTBT verification, as well as results from many pieces of research on specific verification problems. Some posters reviewed the work and technical capabilities of the CTBTO as they stood in 2009. Although some posters presented the work of National Data Centres (NDCs), many were research contributions driven by the authors' individual scientific interests, and so were not necessarily focused on particular obligations of the CTBTO as prescribed in the Treaty.

The CTBTO seeks to derive maximum benefit from the scientific and technical contributions made to ISS09. There was a need to review the work presented and to distil from it those ideas and results which may further the assessment, advancement and refinement of the verification system which is being established under the guidance of the CTBTO Preparatory Commission. The success of ISS09 also offers an opportunity to plan for future interaction with the global scientific community and to guide the priorities for future scientific meetings initiated by the CTBTO. With these aims in mind, the CTBTO has taken steps to ensure that the outcomes of ISS09 are recorded from the perspective of the CTBTO and its future needs. The purpose of this report is to relate existing or promising ideas which emerged at ISS09 to specific scientific and technical challenges which still need to be addressed in the build-up of the CTBTO verification system. The output is the list of proposals which appear in Section 3.

1 The "Provisional Technical Secretariat" of the CTBTO Preparatory Commission is charged with building up the functionality specified under the Treaty. After entry into force of the Treaty it will become the "Technical Secretariat" of the CTBTO. The term "CTBTO" is used in this report for simplicity.

2. Issues of Scope and Approach

2.1. PURPOSE OF ISS

The ISS activity culminating in the June 2009 meeting in Vienna had two stated aims (Dahlman 2009): "to conduct independent assessments of the capabilities and readiness of the CTBT verification regime; and to identify scientific and technological developments that might enhance these capabilities as well as improve the cost-effectiveness of the CTBTO's products and services." This report focuses on the second of these aims, although poster content which addresses the first aim is used, together with the CTBTO's own knowledge of its current capabilities, as an additional indicator to determine proposed topics for future action.

2.2. MAPPING OF TOPICS TO CTBTO FUNCTIONS AND OBLIGATIONS

The ISS09 keynote addresses and posters were organized into scientific subject areas, referred to as 'topics', with external experts appointed as coordinators of each. In practice, many posters related to more than one topic (e.g. "Seismology" and "On-Site Inspection"), and the topics themselves were not mutually exclusive (for example, "Performance Monitoring" and "Data Mining" overlapped with all of the other topics). The advancement of the CTBTO verification system to meet Treaty requirements is based on function (e.g. transmission of data from International Monitoring System (IMS) stations or processing of waveform data) rather than topic (e.g. seismology or performance monitoring). Hence it is necessary to review the full range of ISS09 contributions to find potential input into each of the CTBTO functions which are in need of further improvement.

2.3. ROLE OF THE CTBTO WITHIN THE WIDER VERIFICATION REGIME

The two aims of the ISS quoted above are clearly directed towards assessment of the current capabilities of the CTBTO and ways to improve them. The subtitle of the Science for Security publication, "Verifying the Comprehensive Nuclear-Test-Ban Treaty", implies a wider scope. The broader subject of CTBT verifiability was naturally the focus of many keynote addresses and panel discussions at ISS09 because this is a crucial aspect of the debate in those States which have not yet ratified. In the present report, the focus is restricted to what is required in the build-up of the CTBTO verification system. This distinction is an important one. The tasks to be performed by the CTBTO are defined by the Treaty and its Protocol, and in the United Nations General Assembly Resolution establishing the CTBTO Preparatory Commission. These tasks include the installation and maintenance of the IMS network of stations and radionuclide laboratories; the acquisition, transmission, validation and archiving of data from IMS stations; the automatic processing and interactive analysis by the International Data Centre (IDC) of IMS data to prepare standard IDC products for States Parties; the provision of specified technical services to States Parties; and the development and operation of the on-site inspection (OSI) regime. As required by the Treaty, "operational manuals" are being developed to provide more precise technical details on how each of the CTBTO verification obligations will be discharged after entry into force of the Treaty. The current drafts of these manuals can be used as the basis for determining and prioritizing work which is still to be done. It is assumed that the draft manuals will not change substantially before their adoption at the First Session of the Conference of the States Parties after entry into force.

Although the Treaty imposes an obligation on the CTBTO and its Member States to keep its capabilities abreast of relevant scientific developments[2], there is much in the wider verification field that is explicitly not within the CTBTO remit under the Treaty. One example is to make a final judgement on the nature of any event[3]. It follows that although the widely researched topic of earthquake/explosion discrimination using seismic data remains central to the overall 'verifiability' issue, its relevance to the CTBTO remit is limited to 'event screening', and possibly also to the provision of 'special technical assistance' to Member States. On the other hand, the CTBTO cannot choose to implement its Treaty mandate selectively: monitoring of potential violations underground, in the oceans and in the atmosphere must be assigned equal weight, and all geographical regions must be treated equally.

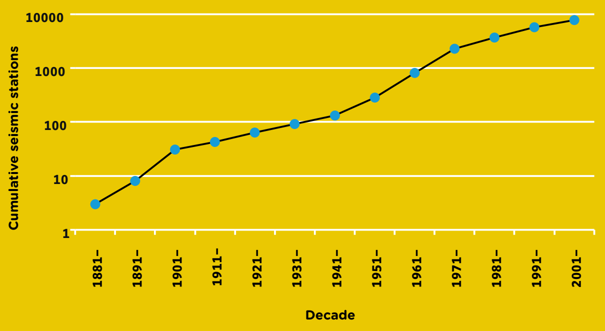
2 "Each State Party undertakes to cooperate with the Organization and with other States Parties in the improvement of the verification regime, and in the examination of the verification potential of additional monitoring technologies such as electromagnetic pulse monitoring or satellite monitoring, ..." (Article IV, paragraph 11, of the Treaty).

3 "These products shall be ... without prejudice to final judgements with regard to the nature of any event, which shall remain the responsibility of States Parties" (Part I, paragraph 18, of the Protocol to the Treaty).

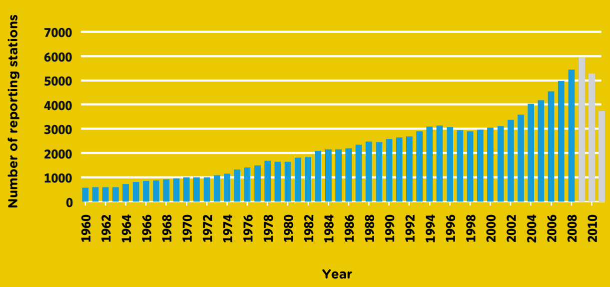
FOCUS

The IMS Seismological Network in a World Context

The registration of new seismological stations, shown in the graph, gives some insight into the historical development of global seismology. In recent years there has been a rapid increase in the number of high-quality seismological stations recording digitally. Although many of these stations are not in the CTBTO's International Monitoring System (IMS), the IMS Primary Seismic Network of 50 stations includes the majority of the world's seismic array stations which offer substantial advantages, especially for the detection of smaller seismic sources and for performing initial location estimates using a single station.



Cumulative number of seismological stations registered with the International Seismological Centre during each decade covering the period 1881-2010 based upon their opening dates (including stations which have since closed). For seismic arrays each seismometer location is counted as a separate station. Temporary stations are generally excluded. Based on data from the International Registry of Seismograph Stations: http://neic.usgs.gov/neis/station_book/station_list.html (retrieved 2 May 2011).



Number of distinct stations reporting at least one observation to the International Seismological Centre for each year from 1960; latest years in grey are as yet incomplete. Data from the International Seismological Centre.

This long history of seismological recording contrasts sharply with the relatively short history of global networks using the other IMS technologies, especially that of global radioactive noble gas monitoring which is still under development.

2.4. NON-IMS DATA AND MATURITY OF IMS TECHNOLOGIES

In reviewing the outcomes of ISS09, it is important to remember that some topics relevant to the CTBTO are mature, while others are new. In particular, global seismology has a history of more than one hundred years (see e.g. Muir-Wood 1988) and the use of seismology in earthquake/explosion discrimination has a history of fifty years. By contrast, global infrasound monitoring is essentially a new technology for which acquisition, processing and interpretation of data are in their infancy. This applies even more to the radioactive xenon detection network currently under development.

Although the Treaty does not provide for the CTBTO to use non-IMS waveform or radionuclide data for routine processing, the CTBTO may be asked by States to provide in-depth analysis of special events, which may include such non-IMS data[4]. Moreover, it would be beneficial to all States if the CTBTO provided capabilities that eased the technical difficulties associated with the integration of non-IMS data and IMS data into schemes for data processing, since NDCs naturally wish to integrate their own data with those of the IMS in the course of their own verification activities. This is particularly true for seismology, which, because of its long history, includes many non-IMS networks providing data which may be useful to States in their assessment of potential Treaty violations. By contrast, there are very few non-IMS infrasound or hydroacoustic stations which could complement IMS data in the investigation of a potential violation, and the same can be said of radionuclide stations. Overall, there is a perceived need for the CTBTO to support Member States in integrating non-IMS data, even though the CTBTO may not routinely use such data itself.

2.5. VIRTUAL DATA EXPLOITATION CENTRE AND DATA MINING INITIATIVE

A general view emerged in 2008 that recent developments in machine learning might offer radical new approaches to the processing of IMS data, in particular in the waveform technologies. This idea was facilitated by ISS09 but predated it, since a number of initiatives in this field were already under way in the CTBTO. This led to "Data Mining" being defined as an ISS09 topic in its own right; workshops dedicated to data mining were held, in which experts from the CTBTO and from the machine learning community exchanged information and educated each other on current capabilities and challenges. From this came an initiative to set up a "virtual Data Exploitation Centre" (vDEC), the plans for which are described in poster **DM-01**. It is intended that vDEC will be an umbrella under which external users can develop, install and test new processing algorithms on IMS data. It is intended that vDEC will provide a forum in which to promote funding of such projects and to provide access to IMS data for researchers. Moreover, a possible role exists for vDEC in the integration of IMS and non-IMS data sources in processing algorithms. It is anticipated that future ISS-like initiatives will be closely associated with vDEC. Some of the initial projects funded by the CTBTO in the data mining field are using the vDEC platform.

There are specific prerequisites for the vDEC initiative (**SEISMO-56** and **DM-01**) to be able to provide a framework for fruitful liaison with the scientific community. The most crucial three are funding, access to data (**SEISMO-32** and **SEISMO-56**) and the unfettered publication of research results by the authors. The funding issue applies to any research initiative. By contrast, inability to access existing data relevant to a research programme is a less common problem, and researchers in the academic community are generally not sympathetic to it. Several posters, including **SEISMO-32** and **SEISMO-56**, touched on this issue. Restriction on the publication of results manifests itself in various ways, one of which may be difficulties in agreeing contractual terms in the award of a contract to an academic institution. Data access and publication restrictions are related, though the latter may also involve intellectual property issues. The marketplace in some research areas of interest to the CTBTO is such that relevant groups may not be easily attracted. For example, in the field of machine learning, researchers have projects with traditionally 'rich' industries such as advertising, banking and medicine, and the chief attraction towards the CTBTO may initially be the intellectual novelty of its problems. In any case, it is important to potential researchers that a clear data access policy for vDEC be in place, covering also the publication of results.

2.6. TECHNOLOGY FORESIGHT

"Technology Foresight" is a CTBTO initiative begun in 2009 to create a platform for long term improvement and upgrading of CTBTO verification capabilities. It provides an electronic discussion forum for internal and external experts concerned with long term response to advances of potential benefit to the CTBTO. Contributions at ISS09 had no direct relationship with the Technology Foresight initiative, though some may contain material relevant to long term updates of CTBTO technologies.

2.7. EXTERNAL FUNDING

An award of funding from the European Union (EU) under its Joint Action 4 programme includes a component entitled "Facilitating the implementation of the CTBT through strengthened cooperation with the scientific community". Initiatives arising from ISS09 provide one element directly relevant to this EU proposal; the Technology Foresight initiative and the vDEC initiative are two others. In addition, national contributions and other funding sources are assured or anticipated. Proposals made in this report are based on the perceived scientific and technical requirements of the CTBTO and are not influenced by prospective funding sources.

2.8. EFFECT OF RAPID TECHNOLOGICAL CHANGE

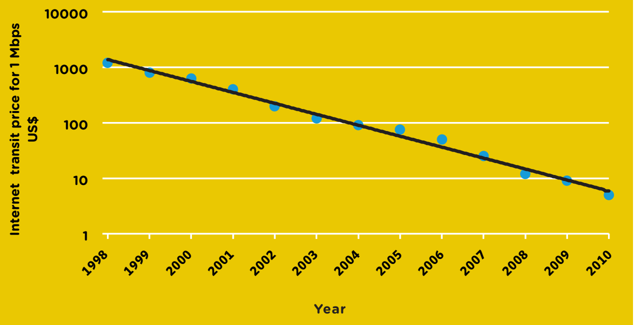
There are some notable respects in which negotiation of the verification aspects of the Treaty was constrained by perceived technological limitations and costs, which have proven to be short lived as a result of rapid technological change in the ensuing fifteen years. One example is the design of the auxiliary seismic network and the way its data are transmitted to the IDC "upon request" and used in IDC processing; the dramatic growth in digital data transmission and computer processing power, and the massive reduction in their unit cost, have drastically altered the way in which data from auxiliary seismic stations could be optimally used for the benefit of verification. Another example is the use of non-IMS data mentioned previously,

4 "The methods for supporting data access and the provision of data shall include the following services: ... (c) Assisting individual States Parties ... with expert technical analysis of International Monitoring System data and other relevant data provided by the requesting State Party" (Part I, paragraph 20, of the Protocol to the Treaty).

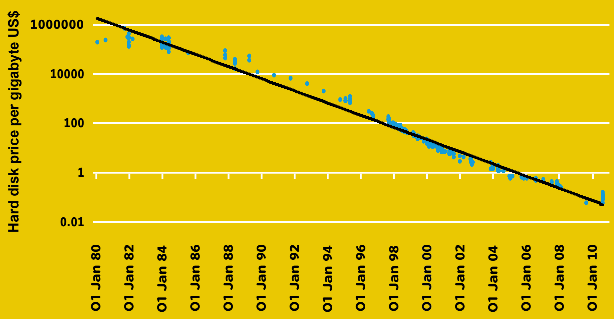
FOCUS

Data Transmission and Data Storage

Both the capacity and the unit cost of near-real-time data transmission have changed dramatically since the Treaty was negotiated, as has the cost of data storage. The graphs give an idea of the rapid rate of change of these indicators over time. When the Treaty was negotiated in the mid 1990s, limitations which are no longer relevant may have exerted a significant influence on the design of the IMS and its data transmission concept, as well as on the mode of processing IMS data at the International Data Cente (IDC).



Internet transit prices in US$ for the US internet region for a bandwidth of one megabit per second, 1998-2010. Data from DrPeering International http://drpeering.net/white-papers/Internet-Transit-Pricing-Historical-And-Projected.php (retrieved 21 Apr 2011).



Hard disk price per gigabyte 1980-2009. Data from "Cost of Hard Drive Storage Space" http://ns1758.ca/winch/winchest.html and "A History of Storage Cost" by M. Komorowski http://www.mkomo.com/cost-per-gigabyte (both retrieved 21 Apr 2011).

which has become technically feasible on a much larger scale simply because of developments in data transmission and data handling methods. Increased use of non-IMS data might be implemented through a greater use of the "Cooperating National Facility" provisions of the Treaty, or through a number of its other provisions; some of the posters touch on such matters (e.g. **HYDRO-03**, **SEISMO-03**, **SEISMO-16**, **SEISMO-32**, **SEISMO-47** and **SEISMO-56**).

2.9. SHORT TERM VERSUS LONG TERM ADVANCES

Improvements may be achieved by actions ranging from simple changes that can be implemented in a few weeks, to major projects to replace existing functionality or add new functionality over several years. Often there is a choice to be made between a number of short term improvements and a longer term solution which may achieve greater benefit but which requires greater resources to develop and more time to implement. The trade-off in such cases sets urgency against potentially greater long term benefit, but with limited resources the short term option may be the only feasible one. Moreover, the method of governance may not provide for the assured long term commitment necessary at the outset when a longer term solution is chosen.

2.10 RE-ENGINEERING AND LIFE CYCLE MANAGEMENT

Despite the obligations imposed upon the CTBTO by the Treaty to keep abreast of relevant technological developments, there has been no comprehensive strategic provision made by the Preparatory Commission for re-engineering of IMS or IDC hardware or software as part of life cycle management. There has been one cycle of IDC hardware replacement and hardware for the Global Communications Infrastructure (GCI) has been replaced as a result of a change in contractor. There has also been some re-engineering of IMS stations. In the IDC, new infrasound processing and analysis software has been developed and there has been substantial development of atmospheric transport modelling software. But life cycle planning has been especially lacking for IDC applications software as a whole. A contrast may be made with the geophysical exploration industry, where complete re-engineering of software applications typically takes place every 10-15 years as part of a life cycle. This is designed both to take advantage of developments in geophysics and computing technologies and to improve functionality on the basis of experience accumulated by industry. This topic was not presented explicitly in the ISS09 posters, but was touched on in some of the keynote addresses. Nevertheless, a significant step was taken with an announcement in September 2010 of a three year re-engineering programme for the IDC applications software.

2.11. PRIORITIZATION

Several factors are relevant in the prioritization of proposals for advancing the CTBTO verification system. No attempt is made to prioritize the proposals here, but some important criteria by which priority could be determined are as follows:

a The deficit between current CTBTO capability and verification obligations imposed upon the CTBTO by the Treaty;

b The staff, financial and other resources required to develop, test and implement a proposal, taking account of any national contributions, cost-free experts or other resources external to those of the CTBTO which may be available and appropriate for a specific project;

c The timescale needed to fully implement the proposal;

d The magnitude of the improvement foreseen in the proposal;

e The risk that the proposed activities will fail, or be superseded by an alternative, or become obsolete owing to changes elsewhere in the system, including as a result of changes to the requirements expressed in the draft operational manuals;

f Considerations of the CTBTO Preparatory Commission or political considerations which may influence the priority of fulfilling requirements mandated by the Treaty.

2.12. RISK

All new initiatives are subject to risk, which should be defined and managed. Generally, the larger the project the larger the risk of wasting resources, because it may not be possible to prove success, or reveal failure, until the final phase. Larger projects also take longer, resulting in an additional risk associated with the lost time in the event of failure.

2.13. SOURCE MATERIAL

The *Science for Security* publication is used as a starting point for the compilation of the proposals presented in Section 3. That publication includes a CD containing re-digitized copies of almost all of the posters. The posters are listed in Appendix I to this report.

3. Specific Proposals

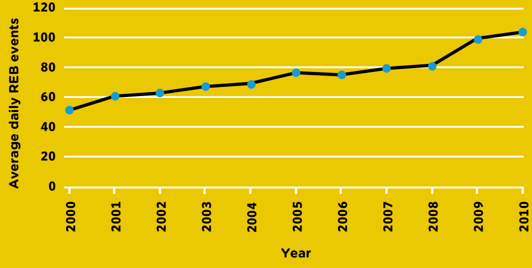
FOCUS

Increasing Size of the Daily Reviewed Event Bulletin

Any seismic or acoustic disturbance which is detected and located by a network of seismic, hydroacoustic and infrasound stations is referred to as an 'event'. By far the most common type of event recorded by the seismic stations is an earthquake; indeed earthquakes dominate the work of IDC waveform analysts, and the problem of discriminating between seismological recordings of earthquakes and explosions has given rise to a whole branch of seismology.

Data from all these IMS waveform stations are processed and analyzed together at the IDC, producing automatic Standard Events Lists (SEL1, 2 and 3), followed by the Reviewed Event Bulletin (REB) after data have been reviewed by analysts.

The graph shows that as the IMS has approached completion, the number of well-recorded events has increased substantially, doubling since daily Reviewed Event Bulletins were first issued by the IDC in the year 2000. Improved processing methods and increased availability of data from IMS stations have also contributed to this increase. Events in the oceans, recorded mainly by the hydroacoustic network, also appear in the REB, and since February 2010 atmospheric events recorded mainly by the infrasound network have also been included. The graph also reflects the progressive increase in waveform analyst workload.



Average number of events in the daily IDC Reviewed Event Bulletin (REB) for each year 2000-2010.

3.1. INTRODUCTION

Proposals are arranged in sections by topic below for ease of reference. The choice of these topics is governed only by the subject matter of the proposals that emerged; they do not follow the ISS09 'topics' or any other formal classification. 'Waveform data processing' is used as a collective term for the processing of seismic, hydroacoustic and infrasound data at the IDC.

3.2. WAVEFORM DATA PROCESSING

3.2.1. Archive of Open Source Waveform Data from IMS stations

Several posters (e.g. **DM-01**, **SEISMO-32**, **SEISMO-55** and **SEISMO-56**) and several coordinators' articles referred to the potential for researchers to address various problems related to the processing and analysis of IMS data. To this end it is proposed that vDEC (Section 2.5) be populated with continuous waveform data from as many IMS waveform stations (including auxiliary seismic stations) as possible through non-CTBTO sources. Many seismic stations, including most auxiliary seismic stations, can be accessed from international data repositories such as the International Research Institutions for Seismology (IRIS) and the Observatories and Research Facilities for European Seismology (ORFEUS). Data from others – in particular most IMS seismic arrays – could be obtained through bilateral arrangements with host countries, since most States which host IMS stations provide open access to the resulting data. For simulation purposes it would be helpful to store the data in such a way that the IMS network and its data sources are simulated as closely as possible. For external researchers it might be beneficial for the data to be available in a format used by the wider geophysical community, such as MINISEED (**SEISMO-55**). This would also help to facilitate simulations which included non-IMS stations whose data were only available in such a format. **DM-16** considers the requirements to support simultaneous availability of all waveform data as required by future data mining applications.

The purpose of this proposal is to provide data from a simulated IMS network to bona fide researchers working on topics of potential benefit to the CTBTO's mission but who would not normally have access to IMS data. This would serve to open up IMS data to a wider range of research contributors, and it would avoid difficulties which might otherwise be encountered when such contributors seek permission to publish research results.

Two topics which might be particularly appropriate for vDEC are those described in Sections 3.3.1 and 3.3.4.

3.2.2.
Short Term Improvements to Automatic Processing of Waveform Data

The pursuit of improvements to automatic waveform data processing at the IDC, especially to reduce the number of false events in its automatic Standard Event Lists, has long been a major issue. For example, this issue was reflected in the first of 12 recommendations made by a waveform experts group on IDC bulletin production in 2003, which were incorporated into the report of the Twenty-First Session of the Preparatory Commission (CTBTO Preparatory Commission 2005). Their adoption by the Commission was a clear indication of the strength of concern of the States Signatories. Improvement is essential in order to reduce the burden of interactive analysis, which is by far the most labour intensive (and therefore a very costly) CTBTO activity. Researchers in the machine learning community have provided promising results in relation to the automatic reduction in false events, the correct assignment of body-wave phase names and the automatic association of arrivals (**DM-02**, **DM-03**, **DM-05**, **DM-07**, **DM-08**, **DM-09** and **SP-12**). Results presented at subsequent workshops and in contract reports have shown much promise, but results presented in ISS09 posters still need further testing, tuning and other improvements before becoming mature enough for operational implementation.

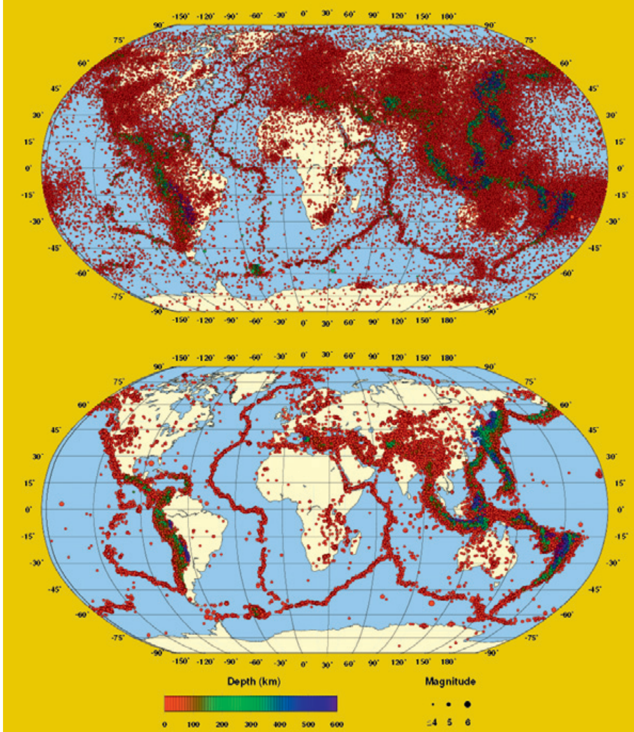
Short term improvements to specific aspects of automatic waveform processing, for example by refining signal detection algorithms and the process of determining ray direction, were already planned

FOCUS

The Problem of Locating Waveform Events

Correct signal association is a major element in the production of a waveform event list. Signals are recorded from many events worldwide at many different stations during any given time period. In order to locate the events it is essential to determine which signals originate from which events, and to 'associate' together those signals belonging to the same event. Errors in this process, which are very common in automatic processing, result in the inclusion of false or 'bogus' events in the list. Such events arise from the association of signals that in reality belong to different events; such events are either non-existent or (if most of the signals are correctly associated) they have gross errors in their computed locations.

The process of association is further complicated by the fact that there may be not just one signal recorded at one station from one event but several signals, corresponding to energy that has travelled along different paths through the sold earth, the oceans or the atmosphere. Incorrect identification of these 'phases' is another source of error in the location of events formed during automatic processing.



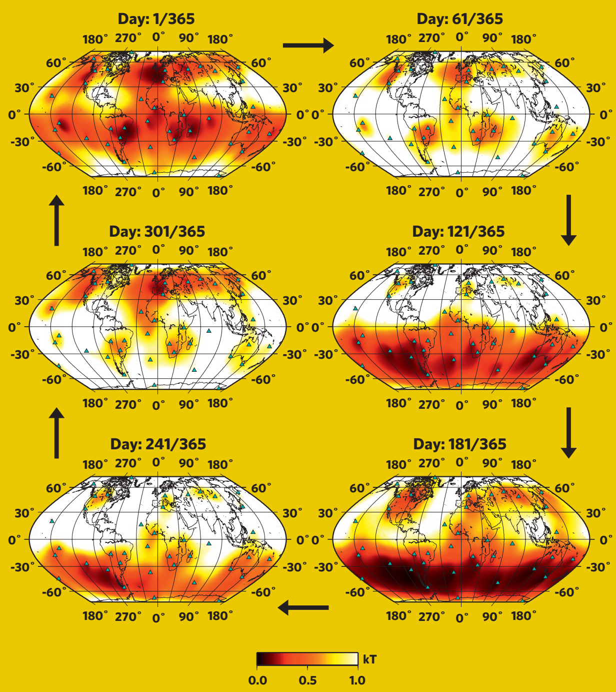
Events included in the IDC automatic Standard Event List 3 (SEL3) (upper plot), and in the event list resulting from interactive analysis (lower plot), for the period January 2005 to March 2009 (202,657 and 142,204 events respectively). (The reviewed Event Bulletin (REB) comprises all those events in the lower plot which satisfy the REB event definition criteria.) The most prominent effect contributing to the different appearance of the two plots is the inclusion of non-existent or poorly located events in SEL3, which result from the incorrect association of signals to events during automatic data processing. From Pearce et al., DM-12.

FOCUS

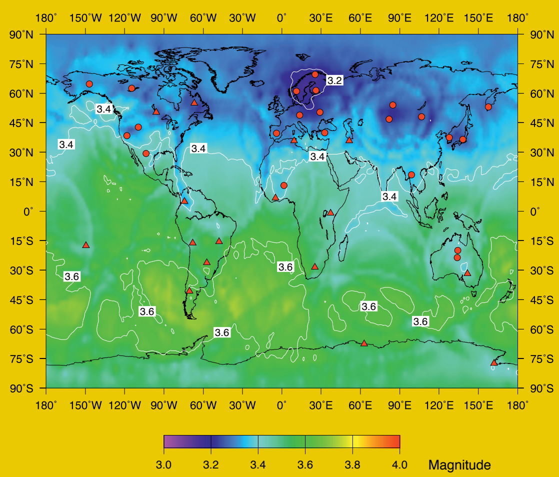
Measuring Event Location Thresholds

In principle, the smallest event which can be detected and located at a given place is an important measure of the effectiveness of a network of seismic, hydroacoustic and infrasound stations. This is the event location threshold. It is influenced by the station distribution, the amplitude and frequency spectrum of background noise at each station (which in general vary with time), and the amount by which signals are attenuated along the different propagation paths from event to station. Location thresholds estimated for events recorded by the IMS usually presuppose that signals at three IMS seismocoustic stations (excluding auxiliary seismic stations) are required to locate an event, because this is a requirement for inclusion in the Reviewed Event Bulletin. But in some cases an event can be well located with fewer such stations, especially if IMS auxiliary seismic stations are also used. It is also often assumed that the signal amplitude must be at least three times that of the noise to declare a detection, in line with the operational setting for automatic processing, whereas in practice smaller signals may be usable depending upon the characteristics of the background noise and of the signal itself.

It follows that conventional methods used to estimate event location thresholds may underestimate IMS network capability. Moreover, the true event location threshold of the IMS network depends ultimately upon the ability of expert analysts to interpret the data with a view to revealing any potential Treaty violation. This ultimate network capability is difficult to quantify, but is likely to exceed that estimated using standard algorithms. For States Signatories, estimating any improvement in event location threshold achievable by including non-IMS stations is also important.



Event location threshold (referred to as 'detection threshold') for sources at each geographic location, estimated for the 39 station IMS infrasound network operational as of October 2008. Detection threshold is defined as the explosive yield (measured in kilotons, kt) at which there is a 90 % probability that two or more stations will detect the resulting pressure signals, and is based upon a minimum single channel signal-to-noise ratio of 1.0 for signal detection. A major source of the seasonal variation is changes in stratospheric wind speed and direction. The estimates utilize a climatological model (Drob et al., 2008) to calculate wind speeds, a global noise survey (Bowman et al., 2007) to provide an infrasonic noise model, and an empirical relationship derived from chemical explosive tests (Whitaker et al., 2003) to relate source yield, stratospheric wind speed and recorded pressure. From Green and Bowers, INFRA-13.



Event location threshold estimated for the IMS primary seismic network for late 2007, when 38 of the planned 50 stations were sending data to IDC. For each point on the earth, the threshold is expressed as the magnitude of the smallest event that would be detected with a 90 % probability by three or more of the stations. Figure from Kværna and Ringdal, SEISMO-15.

before machine learning experts were introduced to the subject; it may be that significant improvements can be made on a shorter timescale by this approach. **DM-10** proposes improved automatic signal detection using an F detector (Melton and Bailey 1957), and **SEISMO-17** proposes an autoregressive method to extract small signals from noise.

3.2.3. Re-Engineering of Applications Software Architecture to Support New Approaches to Waveform Data Processing

It has long been recognized, and the data mining community in particular has pointed out, that the serial 'pipeline', upon which the current automatic waveform data processing is based, limits the scope for improving the quality of automatically generated event lists. Feedback loops between signal detections and the association of these detections with events will assist in building an optimum event bulletin. This requires a fundamental re-engineering of the applications software for automatic processing, as well as a redesign of the data storage concept. A key component of the new architecture will be robust and persistent quality assurance. Data identified as "bad" (e.g. noisy or mistimed) must be masked to prevent their use in downstream processing. New data interfaces must be developed to provide access to these data masks. Moreover, the rigorous identification of bad and missing data will allow more effective use of negative evidence, in which the absence of signals at specific stations can help to locate events and identify erroneous events. Additionally, it will be essential to have data normalization based on a network-wide standard instrument.

A first step will be to specify requirements for long term changes to the automatic waveform processing architecture to facilitate the integrated detection and association of arrivals (**DM-02** to **DM-09** and **SP-12**). In the long term, waveform data will be used in multiple stages of data processing for hypothesis testing and feature extraction, and if this is to include not only current but also historical waveforms, the current method of storing waveform data may be unsuitable. **DM-16** presents ideas on an alternative scheme. Bearing in mind the strategic importance of this in facilitating longer term improvements, it is suggested that this could be one topic to be addressed by a group of experts, who could take into account the geophysical, software, hardware and performance aspects of the problem.

3.2.4. Unassociated Arrivals in Waveform Data

The large number of unassociated arrivals in waveform data is of concern because each one is potentially 'suspicious', and many such arrivals can still not be associated even when national bulletins are used to lower the global threshold of completeness (**SEISMO-09**). It is proposed to address systematically the problem of unassociated waveform arrivals with a view to improving our understanding of their origins.

3.2.5. Modern Visualization Methods Applied to Waveform Analysis

Several long awaited aids to the interactive analysis of (especially seismic) data are now being actively pursued by the CTBTO. These include F and F probability traces to assist analysts in correct identification of the azimuth and slowness of seismic signals at array stations; conversion of displayed seismograms to a common instrument response; and an adaptive filter to extract small signals from seismic array data. The latest graphical visualization tools may offer additional scope for assisting analysts in the assessment and manipulation of waveform data.

A requirements study for enhanced visualization tools should be closely coordinated with other studies related to automatic processing. The potential for advanced visualization tools to aid the analysis and interpretation of IMS data emerges also from some posters, for example **DM-16**.

3.3. SEISMIC MONITORING

3.3.1. Simulations Using Auxiliary Seismic Data as Primary Seismic Data

It is proposed to study the benefits of processing and analysing auxiliary seismic data in the same way as primary seismic data (**SEISMO-12**). This will allow a more realistic demonstration of the verification potential of IMS seismic data, and will demonstrate global network performance and bulletin completeness compared with the current operational mode.

Irrespective of restrictions imposed by the draft IDC Operational Manual on the CTBTO's utilization of IMS auxiliary seismic data, any State Signatory could in principle process the primary and auxiliary seismic data together continuously at its NDC. However, this is not currently practicable because the CTBTO may not receive and forward auxiliary seismic data continuously except in special, approved circumstances.

The proposed study would also feed any debate on the changing of Operational Manual guidelines on how the CTBTO processes IMS auxiliary seismic data; these guidelines include the current exclusion of auxiliary seismic data from 'event definition criteria', which are to be met before an event can be included in an automatic event list or the Reviewed Event Bulletin (REB). This proposal would fit well with the aims of vDEC (Section 2.5).

A demonstration performed by external experts which showed the verification related benefits of using auxiliary seismic data more extensively might be a powerful factor in support of future changes to how auxiliary data are processed in the IDC. Moreover, any such demonstrated benefit would be additional to the other well known technical advantages of receiving auxiliary data continuously. These include: securing the data for later data requests as required by the Treaty; guarding against NDC requests for large amounts of auxiliary data degrading the response to operational data requests or resulting in a 'denial of service' situation; and providing more stable and timely transmission of auxiliary seismic data (including state of health information) to the IDC using the continuous data protocol.

3.3.2. Improved Automatic Processing of Three Component Seismic Data

Most IMS auxiliary seismic stations, and some primary seismic stations, use three component sets of seismometers. Currently, the CTBTO does not process three component seismic data optimally. **SEISMO-14** proposes methods based on particle motion to validate three component signals recorded at regional distances, and signals from surface reflections. Improvements in three component processing of seismic data are currently being pursued by the CTBTO.

Another problem arises in that the current automatic processing is not routinely configured in a way that allows detection of signals in three component data unless all three components are functioning; in these circumstances signals must be detected manually by analysts. More work is required to optimize signal detection in the absence of three fully functioning components.

3.3.3. Improvements to Global Seismic Wave Speed Model

There is a consensus that more work needs to be done to improve regional seismic travel time corrections. There are also arguments in favour of introducing corrections at teleseismic distances, bearing in mind that time-defining seismic arrivals in events recorded in the REB are mostly teleseismic P waves. Several posters consider improved wave speed models, including **SEISMO-02**, **SEISMO-03**, **SEISMO-06**, **SEISMO-07** and **SEISMO-11**. **SEISMO-45** describes a scheme for triangular tessellation which is suitable for spatially variable resolution appropriate for use in subsurface wave speed models. **DM-11** presents results of a machine learning application to this problem using a large data set from REBs. Improvement of the P wave speed model is the primary factor in reducing event location error (and especially location bias). However, other seismic phases may contribute. For example, a proposal to improve location and magnitude using arrival times of the regional phase Lg was made in **SEISMO-14**.

3.3.4. Integration of Non-IMS Data into the Verification Process

In the future, States Parties may require the CTBTO to utilize non-IMS data in the analysis of special events, and they will in any case require a capability to combine IMS and non-IMS data (especially seismic data) in their national verification activities. It is also useful to include non-IMS stations in the assessment of network capability, and to use non-IMS stations to test proposed geographical changes to locations of IMS waveform stations.

One illustration of the importance of non-IMS seismic stations is provided by **SEISMO-27**, which uses data from openly available non-IMS stations in a study of the first announced nuclear test by the Democratic People's Republic of Korea in 2006. Studies involving the integration of non-IMS data would be greatly facilitated by having access to open source IMS seismic data in vDEC, as proposed in Section 3.2.1.

3.4. HYDROACOUSTIC MONITORING

3.4.1. Improvements in Classification of Hydroacoustic Signals

Acoustic signals recorded at hydrophones from in-water explosions (H phases) have until recently been recorded only rarely at IMS stations, yet their reliable identification is crucial to verification. Moreover, the correct classification of T phases and noise phases is important for correct association of signals recorded at different stations, and event building. The CTBTO is actively addressing this problem and has achieved considerable recent improvements using a machine learning approach, which is described in **DM-06**, though the correct identification of signals recorded at T phase stations from in-water explosions remains problematic.

3.4.2. Refinement of Hydroacoustic Wave Speed Model

Lateral variations in acoustic wave speed in the oceans result in lateral refraction of signals, which can result in a large event location error over the long path lengths typical of IMS hydroacoustic signals; this degrades the otherwise high precision with which the IMS hydrophone triplets can measure signal back-azimuth. **HYDRO-13** presents data on lateral refractions leading to non-great-circle ray paths.

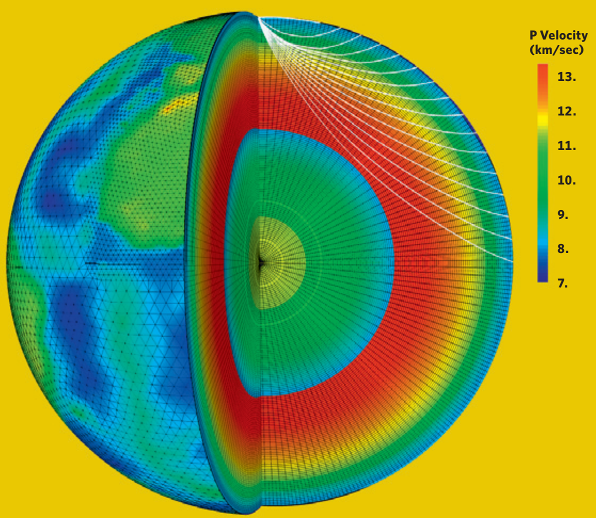
3.4.3. Use of Mobile Buoy System as Backup for Hydrophone Stations

Experience with IMS hydrophone stations has revealed their vulnerability to premature failure. Consideration has long been given to the possibility of using buoy based installations as temporary mitigation (e.g. **HYDRO-03** and **HYDRO-04**). This option is of interest in view of the high capital cost and logistical difficulty of carrying out repairs, and because of the lack of redundancy in the IMS hydroacoustic network. However, the cost-benefit ratio of developing and deploying a temporary buoy system depends also on the contribution of other parts of the IMS network (notably the seismic stations) to the detection of in-water explosions.

FOCUS

The Importance of Seismoacoustic Wave Speeds

The speed at which seismic waves travel at different points within the earth is an important diagnostic in many fields of earth-science research; the same can be said of acoustic wave speeds in the oceans and in the earth's atmosphere. The primary importance of wave-speed information in CTBTO is for event location. Errors in the wave-speed model used for the atmosphere, oceans and solid earth all lead to degradation of event location quality. The ability to correctly and precisely locate a potential Treaty violation is an important component of verification, which could lead ultimately to the choice of a region for an On-Site Inspection (OSI). Hence it is understandable that ISS09 assigned high importance to the improvement of wave-speed models for all three media (Sections 3.3.3, 3.4.2 and 3.5.1).

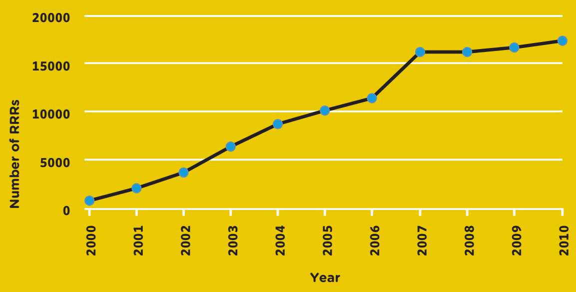


Triangular tessellation capable of representing both uniform and variable resolution wave-speed fields over the earth, and used in the evaluation of published three dimensional wave-speed models and to represent new models. This form of tessellation overcomes the increase in longitudinal resolution towards the poles which is inherent in conventional tessellations, while it also provides for smoothly varying spatial resolution convenient for computation. From Ballard et al., SEISMO-45.

FOCUS

Emergence of the Network of IMS Radionuclide Particulate Stations

Each radionuclide particulate station is scheduled to contribute one full spectrum per day, so the number of reviewed gamma-ray spectra relates directly to the number of stations, minus any station downtime. The graph therefore traces the development of the IMS radionuclide network as well as the increasing radionuclide analyst workload.



Number of full gamma-ray spectra reviewed from radionuclide particulate stations for each year 2000-2010; each spectrum results in a Reviewed Radionuclide Report (RRR).

3.5. INFRASOUND MONITORING

3.5.1. Improvement of Time-Varying Atmospheric Acoustic Wave Speed Models for Locating Infrasound Events

The precision of locating infrasound events using the IMS network depends crucially on the continuously varying acoustic wave speed profile of the atmosphere, which includes seasonal, diurnal and more rapid variations. The use of atmospheric models to determine location- and time-dependent wave speed as well as station specific detection thresholds (INFRA-05 and INFRA-13) has shown that there is much scope for improving location precision and estimates of network capability; this is currently being pursued in the CTBTO. Calibration events such as that in Israel described in INFRA-09 provide important observational data.

3.5.2. Alternative Methods of Detecting and Locating Infrasound Events

INFRA-04 and INFRA-06 describe methods somewhat different from those currently employed by the CTBTO.

3.5.3. Improvements in Classification of Infrasound Signals

Although the CTBTO has made major advances in infrasound signal classification, there is scope for further refinement using a machine learning approach (e.g. DM-15). Relevant theoretical work includes the interpretation of infrasound signal codas using full-waveform modelling (INFRA-10). INFRA-21 highlights the importance of gas flares as a source of noise.

3.6. RADIONUCLIDE MONITORING

3.6.1. Towards Improved Sensitivity of IMS Radionuclide Particulate and Noble Gas Stations

Simulations reveal that the 40 station IMS noble gas network for detecting radioactive xenon could benefit from improved coverage, for example in the western Pacific Ocean. The Protocol to the Treaty (Part I, paragraph 10) provides for additional IMS noble gas stations after entry into force, but meanwhile the sensitivity of existing and planned stations can be improved. Although this is partly a problem of decreasing the background levels of radionuclides in the atmosphere (as discussed in Section 3.6.2), it is also an engineering problem in station design with promising avenues to explore (RN-09 and RN-11). RN-25 considers improvements to equipment designed to reduce the minimum detectable concentration of radioactive xenon. Nevertheless, even after the detection capability of the stations has improved, there will be scope for optimizing their distribution.

3.6.2.
Reduction of Global Radioactive Xenon Background

Another way to improve the sensitivity of measurement of xenon released as a result of a Treaty violation is to reduce the radioactive xenon background. Several posters address this issue (RN-01, RN-02, RN-03, RN-04, RN-07, RN-19, RN-27, ATM-15 and ATM-16). A crucial aspect would be the implementation of engineering solutions at radiopharmaceutical plants and other installations which release radioactive xenon, in order to reduce its release to the atmosphere. It would be especially attractive if new facilities were designed at the outset for the retention of noble gases, since this is much easier to do than modifying existing facilities.

3.6.3.
Improvement of Reliability of IMS Radionuclide Particulate Stations

Improving the reliability of IMS radionuclide particulate stations is an engineering problem already being addressed by the CTBTO. Experience since the first stations were installed has confirmed that the most crucial (but not the only) aspect is improving the reliability of cryogenic cooling of detectors at the station (RN-12 and RN-13).

3.7.
ATMOSPHERIC TRANSPORT MODELLING

3.7.1.
Atmospheric Transport Modelling with Increased and Spatially Variable Resolution

Several posters address the spatial resolution of atmospheric transport modelling (ATM-02, ATM-03, ATM-06 and ATM-08). A global increase in the resolution is planned for implementation at the CTBTO. Work has shown that, especially near stations in complex topography, models would benefit from greater resolution in those areas, and that a more optimum efficiency would be achieved if a location dependent resolution were adopted, using adaptive grids. This is currently being investigated within the CTBTO.

FOCUS

The Cooling of Gamma Ray Detectors at IMS Radionuclide Stations

The germanium gamma ray detectors used to measure radionuclides at IMS stations must be operated at the boiling point of liquid nitrogen, which is close to –200 C. In a laboratory setting, where there is adequate electric power and the necessary equipment, the provision of liquid nitrogen is routine and this provides a well-established method to cool such detectors. However, providing a supply of liquid nitrogen at IMS stations, many of which are remote and/or unmanned, poses special difficulties, and instead the detectors have traditionally been cooled electrically using principles analogous to those used for refrigeration.
Such methods have proved much less reliable than liquid nitrogen, and this unreliability is compounded by adverse effects on the detector which may result from a cooling failure. In 2009, one half of the down time of IMS radionuclide particulate stations was caused by the failure of detector cooling.
Accordingly, this has become a high priority engineering issue within CTBTO.

3.7.2.
Further Investigations into Ensemble Modelling

ATM-04 and ATM-05 consider methods by which different models are compared and combined in ensemble modelling.

3.8.
EVENT SCREENING

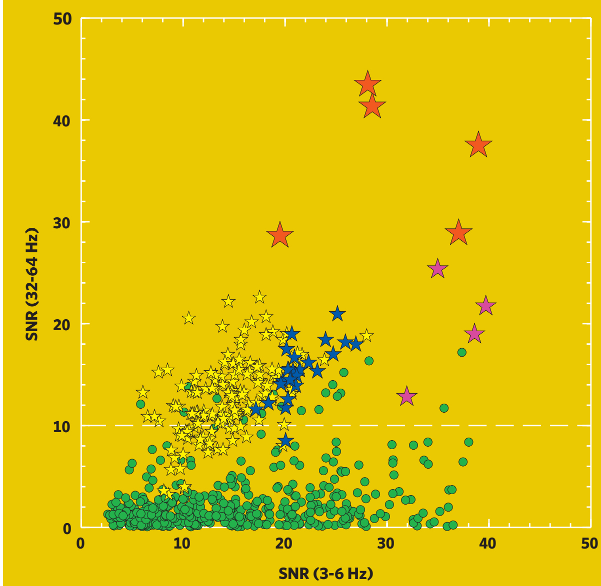
3.8.1.
Revision and Enhancement of Waveform Event Screening Criteria

The Treaty imposes a specific obligation on the CTBTO to perform event screening and to issue event-screened products. Event screening is the automatic application of approved criteria to 'screen out' events which are believed to be consistent with natural phenomena; this results in a Standard Screened Event Bulletin. Central to event screening

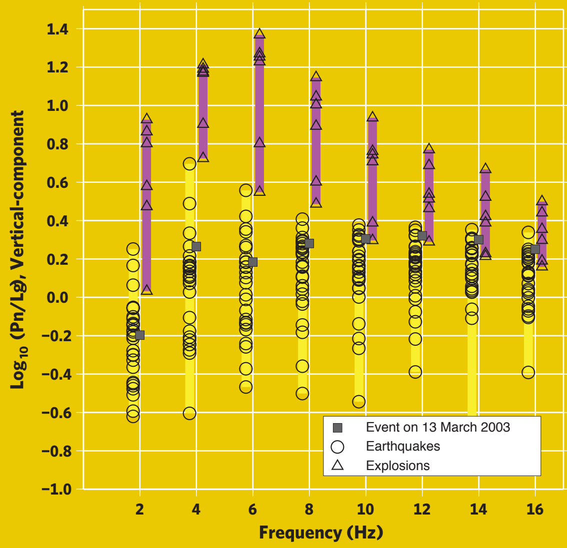
FOCUS

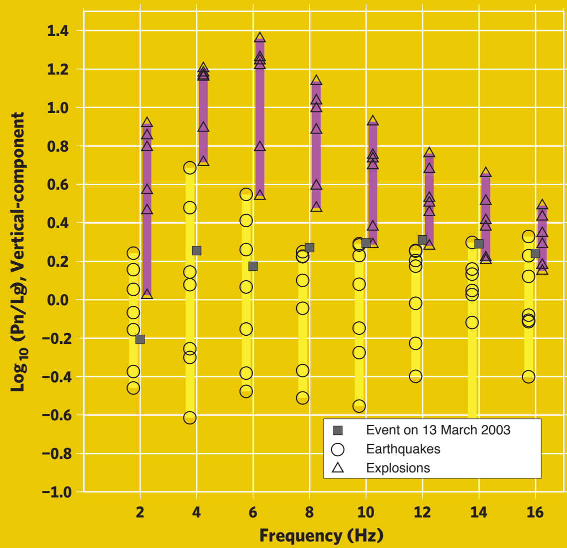
Event Screening

If a potentially suspicious event under the Treaty is detected and located, the question of identifying its origin will become paramount. Although the Treaty specifies that CTBTO does not make a final decision on the nature of any event (see footnote 3 in Section 2.3), event screening can be useful in this process. Event screening seeks to 'screen out' events "considered to be consistent with natural phenomena or non-nuclear, man-made phenomena" (Part I, paragraph 18(b), of the Protocol to the Treaty). Standard tests, using well-established methods of identifying events which cannot be explosions, are applied automatically in order to select events to be screened out. Intuitively, event screening becomes more efficient as the methods are refined to allow more non-suspicious events to be screened out. However, the essential measure of the success of event screening is that the list of screened out events must never include a nuclear explosion. Since there are relatively few data from nuclear explosions, which have occurred in very few locations, the development of robust automatic screening criteria which can still screen out a large percentage of events is a major challenge. This is reflected in the emphasis placed on this topic in the ISS09 outcomes.



High-frequency energy content (signal-to-noise ratio in db for the 32-64Hz band) plotted against low-frequency energy content (signal-to-noise ratio in db for the 3-6Hz band) for the Chase 21 in-water chemical explosion (red asterisks). Also shown are 1996 and 1998 Japanese refraction experiment explosions (400kg in magenta, 40kg in blue and 20kg in yellow), and presumed earthquakes in the REB (green circles), recorded at non-IMS station Point Sur (California) and at Wake Island (IMS station HA11). Since small in-water explosions are not detected seismically by the IMS, a high-frequency-band screening line could be set to 10db (dashed line) and then applied only to events for which there were associated seismic signals, without fear of screening out detected explosions. From Jepsen and Fisk, HYDRO-06, incorporating an update from the authors.





Measurements of the spectral amplitude ratio between P- and S-waves for seismic events that occurred near Lop Nor, Xinjiang, China. Amplitudes were determined from eight frequencies using the crustal phases Pn, Pg and Lg, on vertical recordings. The known nuclear explosions (triangles, with the full range marked in magenta) consistently have higher values than earthquakes (circles, with range in yellow). The event of 13 March 2003 (squares) clearly falls in the earthquake population, but shows relatively strong amplitudes at high frequency band 10-16 Hz. Upper panel: 20 seismic events near Lop Nor test site reported in REB (mb > 3.4) and seven additional events from International Seismological Centre (ISC) bulletin are plotted. Lower panel: Seven seismic events with magnitude mb > 4.5 and six known underground nuclear explosions at Lop Nor test sites are plotted to examine for magnitude bias on spectral ratios. From Kim et al., SEISMO-27, where details of all events are given.

is an overriding aim not to screen out an event which may be suspicious under the Treaty. Criteria which contribute to event screening, and which can thus potentially help to identify the nature of an event, are often referred to as discriminants.

The current waveform event screening criteria were introduced 'experimentally' and were always expected to be reviewed, refined and validated. The second announced nuclear test by the Democratic People's Republic of Korea in 2009 focused attention on the mb:MS criterion, which has led to recommendations by Working Group B of the Preparatory Commission to modify parameters used to calculate the criterion, pending further studies. Several posters, including **SEISMO-21**, **SEISMO-22**, **SEISMO-25**, **SEISMO-26** and **SEISMO-27**, report on seismic event screening methods. Additional event screening criteria are yet to be introduced – for example, a joint seismic–hydroacoustic criterion to screen out oceanic earthquakes (**HYDRO-06** and **HYDRO-07**).

3.8.2. P/Lg as Discriminant

Sykes and Richards (2009, p. 9) stated that the ratio of high frequency P to Lg amplitudes observed at regional distances is a reliable discriminant even for smaller events. They expressed a need for more work on this to be carried out in regions far from established test sites; this would potentially result in improvements to event screening criteria.

3.8.3. Moment Tensor Focal Mechanisms as Discriminant and Depth Estimator

Sykes and Richards (2009, pp. 8-9) pointed out that centroid moment tensors provide a means to discriminate between earthquakes and explosions, and provide an estimate of focal depth. These authors also pointed out that the established methods are not focused on smaller events: the methods use signals with a period range of between 30 and 100 seconds, which favours success for larger events only, and they provide poor depth resolution. In addition, there are degenerate components of the moment tensor for focal depths small compared with the signal wavelength used, and the predominance of observed S waves at longer periods results in the inability of these methods to resolve any explosive/implosive component of the moment tensor. **SEISMO-21** and **SEISMO-26** present moment tensor methods used at smaller magnitudes, and SEISMO-36 proposes a method for continuous moment tensor monitoring. **SEISMO-14** uses pP, sP, Lg and Rg phases to better determine depth.

A method which utilizes this information in a way that is specifically geared to smaller events, and to the explosive as well as the deviatoric component, is the relative amplitude method of Pearce (1980) and Pearce and Rogers (1989). This method also emphasizes the importance of confidence measures for moment tensors, and this emphasis is shared by **SEISMO-21**, which uses the method of Hudson et al. (1989) to display moment tensors with confidence ellipses. Sykes and Richards (2009) argue for more work on the use of moment tensors to determine focal mechanism and depth, in support of better event screening.

3.8.4. Radionuclide Event Screening

Although there were few contributions at ISS09 on radionuclide event screening, one aspect touched on is the use of a machine learning approach to the identification of radioactive xenon sources from isotope ratios (**DM-17**).

3.9. DATA TRANSMISSION

3.9.1. Future Changes in the GCI

Rapid changes in communications technology and costs, and the evolving needs of global data communication, suggest that the GCI of the future will look very different. **SP-09** and **SP-10** address this issue. A further examination of options for access to the GCI by other users (e.g. other seismological networks (**SP-09**)) is one of many possibilities that can be examined in a forward look that addresses IMS data transmission.

FOCUS

Test-Ban Verification and Gas Transport Beneath the Earth's Surface

The detection of relevant radionuclides offers potentially the most compelling positive evidence of a nuclear explosion. For a fully contained underground nuclear explosion, detection by this means would rely upon the capacity of gaseous radionuclides to permeate from the underground detonation point to the earth's surface, where they could be detected by measurements either in the air or the soil. The ability of gaseous material to travel through the rock mass to the surface is influenced by many factors, ranging from rock type and its fracture pattern to barometric pressure changes in the atmosphere above. The efficiency of this process is important both for the interpretation of IMS noble gas observations and for the planning and conduct of any potential On-Site Inspection. Although many of the contributing processes may be well understood, there are many factors whose relative contribution may depend upon specific circumstances, and past observational data are sparse. Behaviour is therefore not well known, and it is in this context that the outcomes of ISS09 focus on this topic.

3.10. ON-SITE INSPECTION METHODOLOGY

3.10.1. Review of Capabilities of Each Prescribed OSI Technology Which Are Relevant to the Treaty Mandate

Some posters (e.g. OSI-01, OSI-11 and OSI-13) consider the capabilities and limitations of OSI methods. The need to consider this issue was also emphasized in the article by Li (2009, pp. 44-45). Evidence of the ability or inability of various geophysical methods to detect the persistent effects of an underground explosion in different circumstances comes from theoretical considerations or from practice. Relevant experience may be found in the exploration industry as well as in the land remediation industry, archaeological science and academic research in shallow geophysics. For radionuclide methods, much is known from the monitoring of reactor sites. A catalogue of the types of subsurface disturbance which might result from a Treaty violation could be compiled, together with a record of the capabilities and limitations of each prescribed method to detect such a disturbance and, where this disturbance should be detectable, the optimum configuration and parameters necessary for detection by the relevant method(s). For example, it would be of value to examine the circumstances (if any) in which a microgravity survey could yield results of relevance to an OSI.

OSI-31 and OSI-34 consider the detection of very small seismic signals relevant to OSI. OSI-21 considers the observation of anomalous gamma ray spectra. OSI-18 considers the identification of radionuclide signatures from nuclear tests, and OSI-19 presents a hand-held gamma ray detector with increased capabilities. OSI-20 addresses methodologies for OSI overflights.

Other posters present advantages of using technologies not contemplated by the Treaty to identify 'ground zero'. In particular, OSI-13 and OSI-15 consider interferometric synthetic aperture radar (InSAR), OSI-14 discusses satellite imagery and OSI-40 describes geomagnetic disturbances which may be detected resulting from interaction of an acoustic wave with the ionosphere.

3.10.2. Small Scale Field Exercises to Detect Relevant Deep Targets

Li (2009, p. 45) pointed out that "The OSI regime's capability to detect deep targets has not been sufficiently or effectively tested yet." Such exercises would not need to be carried out under the formal constraints of OSI procedure, but can be carried out at a suitable field location where target anomalies exist or are simulated.

3.10.3. Physical Mechanisms of Underground Gas Transport

Studies of physical mechanisms of underground gas transport are recommended by Li (2009, p. 45), and an example is presented in OSI-26. They include mechanisms associated with the zone immediately surrounding an underground nuclear explosion and are relevant to the detection of radioactive xenon by the IMS network. Other examples of underground gas transport studies are given in OSI-24 and OSI-25. OSI-27 presents a concept of operations for noble gas sampling.

3.10.4. Formal Methodology for Defining Priorities Within the Inspection Area

The great challenge of performing an exhaustive OSI throughout an area as large as 1000 square kilometres, the maximum area allowed by the Treaty, is well known. OSI-10 proposes a scheme for formalizing the process of focusing the inspection effort based on an integration of all data sources as they become available before and during an inspection. OSI-14 suggests a strategy for OSI planning.

3.10.5. Systems Approach to OSI

OSI-07 and OSI-09 present a systematic approach to OSI. Both posters introduce the use of evaluation matrices to develop the OSI regime. OSI-09 introduces technology evaluation matrices to assess technology development priorities for stages leading to OSI readiness at entry into force of the Treaty. OSI-07 presents the use of such matrices to identify the best application of each OSI technique for particular underground nuclear explosion scenarios.

3.11. PERFORMANCE MONITORING

3.11.1. Capture of More Information During IDC Processing and Analysis

It has long been known that one impediment to the measurement of IDC system performance and analyst performance is the inadequate retention of parametric data associated with intermediate processing and analysis steps. This inadequacy also prevents the re-creation and posterior justification of IDC results as required by the Treaty. In addition, the retention of more intermediate processing information will provide a richer environment for machine learning projects that use parametric data in the quest for higher quality event bulletins. This problem could be addressed by a study group to specify requirements.

3.11.2. Relative Value of IMS Stations in Verification of Treaty Compliance

It is well known that there is a wide variation in the contributions made by data from different IMS stations to global event bulletins and global radionuclide coverage, whether based on contributing signals or on cost per unit of data. This applies for various reasons to all IMS technologies. In the interests of cost effectiveness, such differences need to be investigated and steps taken to make the network more optimal (SEISMO-10 and SEISMO-15). In the future it should become politically feasible to seek changes to the distribution of IMS stations, as stated in the Treaty provision for "the improvement of the verification regime" (Article IV, paragraph 11), and the implementation of this proposal would prepare for such a discussion.

3.11.3. Improved Methods of Performance Monitoring

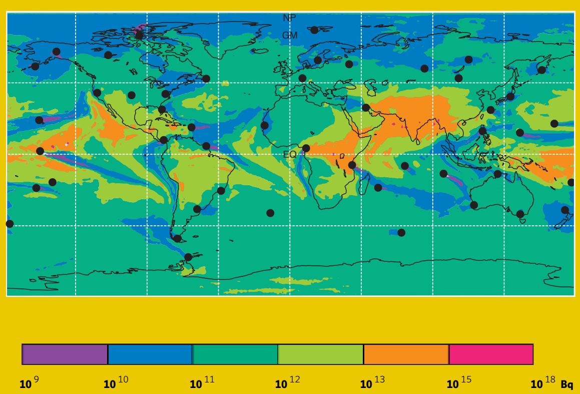
Many improvements could be made to the monitoring of performance. Proposals are made in many of the posters under "Performance Monitoring". Some, such as analyst performance, are being addressed by the CTBTO, and the CTBTO currently has contractors working on the computation, display and evaluation of performance metrics. However, the objective monitoring of analyst performance remains a complex area in need of further work. Models to measure system performance are suggested (SP-07, SP-14 and SP-19), as is a methodology for the automatic quality control of verification data (SP-07). Performance measurement for seismic events is addressed by SEISMO-13, and SEISMO-11 describes a method of using teleseismic arrivals to check for timing errors at seismic stations.

FOCUS

The Relative Contribution of IMS Stations to Verification

Now that a near-complete IMS network has been operating for several years, we can begin to make predictions of the relative contribution of each station in the verification effort after Entry into Force of the Treaty. Although the IMS is designed to provide global coverage, the relative contribution of stations towards the verification system can vary markedly as a consequence of various factors. Although the Treaty specifies a monitoring role for all IMS stations, attention to cost-effectiveness, plus the possibility of future network enhancements, suggests that the relative contribution of stations to IDC products, or to States Parties' verification capability in general, may be important indicators. Such indicators might also be useful for prioritizing sustainment of IMS stations in the context of limited resources.

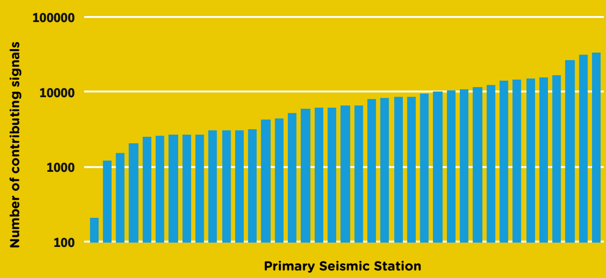
The coverage of individual radionuclide particulate and noble gas stations is determined mainly by the prevailing patterns of atmospheric transport, which have strong directional preferences; this leads to some radionuclide stations being more effective at sampling certain areas of the earth than others (Section 3.6.1).



Detection threshold for a release of Ba-140 and its daughter product La-140 at each point on the earth's surface, averaged for September 2008 and based upon the network of IMS radionuclide particulate stations operating at that time. Ba-140 is used as a benchmark for IMS station design. The threshold is expressed in becquerels at the source, and requires detection above the minimum detectable concentration at any one station in the network, with allowance for decay time. The Figure shows a typical month, but seasonal variations arise from changes in atmospheric wind patterns, which in turn dictate which stations are able to detect releases at a given place. The generally higher threshold in the equatorial region is a typical feature of these maps, and arises from a combination of atmospheric transport patterns and the station distribution. From Becker and Wotawa, ATM-03.

The contribution of seismic stations depends strongly upon the ambient background noise level at each station, but is also influenced greatly by the uneven distribution of earthquakes worldwide. Although this influence may be considered a distortion of the true value of an IMS seismic station (because the IMS seismic network is designed to detect and locate nuclear explosions which might occur anywhere), it remains true that as many events as possible must be located in order to reveal potentially suspicious events among the dominating earthquake population, and this task is made easier if stations are appropriately distributed to record and locate earthquakes.

Although there are many ways of measuring the 'contribution' of a seismic station, the metric chosen for the graph does serve to show that the variation in contribution is large.



Contribution of each IMS primary seismic station as measured by the number of signals contributing onset times to location estimates of events in the Reviewed Event Bulletins for 2009. Stations are sorted according to their contribution. No correction is made for station outages, but these do not have a major effect on the graph.

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POSTERS

Appendix 1

POSTERS PRESENTED AT THE ISS CONFERENCE

ATMOSPHERIC TRANSPORT MODELLING

ATM-02/E: High resolution atmospheric transport modelling to support source location estimates (D. Arnold, A. Vargas and P. Seibert)

ATM-03/E: On the PTS in-house capacity building in atmospheric transport modelling during the past decade with an outlook on scheduled improvements in support of the noble gas verification regime (A. Becker and G. Wotawa)

ATM-04/E: Application of BMA approach to multi-model atmospheric dispersion ensemble system for emergency response (S. Galmarini and S. Potempski)

ATM-05/E: Comparison of EPS-based ensemble of atmospheric dispersion predictions and multi model performance (S. Galmarini, S. Potempski, F. Bonnardot, A. Jones and L. Robertson)

ATM-06/E: Review of the methodology used for global backtracking of anthropogenic radionuclides (A. Panday)

ATM-07/E: WMO/CTBTO “atmospheric backtracking response system” implementation at ZAMG (P. Skomorowski, P. Seibert and U. Pechinger)

ATM-08/E: Current issues in atmospheric transport modelling and source location for CTBT verification (P. Seibert)

ATM-09/E: The operational CTBTO–WMO atmospheric backtracking response system for CTBT verification – Status and plans (G. Wotawa and A. Becker)

ATM-10/E: A refined backtracking and source reconstruction for the noble gas measurements taken in the aftermath of the announced October 2006 event in North Korea (A. Becker, G. Wotawa, A. Ringbom and P.R.J. Saey)

ATM-11/E: Atmospheric transport of natural radionuclides simulated in tropical regions by a General Circulation Model (P. Heinrich, A. Jamelot, L. Vignon and Y. Grillon)

ATM-12/E: Construction of radioxenon artificial data set for the 2008 IEEE International Conference on Data Mining (K. Ungar et al.)

ATM-14/E: North Korean nuclear test of October 9th 2006: The utilization of Health Canada’s radionuclide monitoring and Environment Canada’s atmospheric transport modelling (T.J. Stocki et al.)

ATM-15.1/E: Changes in radioxenon observations in Canada and Europe during medical isotope production facility shut downs in 2008 (K. Ungar et al.)

ATM-15.2/E: Changes in radioxenon observations in Canada and Europe during medical isotope production facility shut downs in 2008: Annex (K. Ungar et al.)

ATM-16/E: Global distribution of the radioxenon background caused by known civilian emissions and its consequences for CTBT verification (G. Wotawa et al.)

DATA MINING

DM-01/A: Strategic initiative in support of CTBT data processing: vDEC (virtual Data Exploitation Centre) (S. Vaidya, E.R. Engdahl, R. Le Bras, K. Koch and O. Dahlman)

DM-02/A: Machine learning for improved automated seismic event extraction (A. Kleiner, L. Mackey and M.I. Jordan)

DM-03/A: Support vector regression for phase arrival prediction and SEL3 event evaluation (H.A. Kuzma, E.R. Engdahl and J.W. Rector)

DM-04/A: Generative graphical models for classification of seismic signals (C. Riggelsen, M. Ohrnberger and F. Scherbaum)

DM-05/A: Supervised classification for improving automatic labeling of phase and identifying false associations (J. Schneider et al.)

DM-06/A: Kernel-based machine learning techniques for hydroacoustic signal classification (M. Tuma and C. Igel)

DM-07/A: Applying machine learning methods to improve efficiency and effectiveness of the IDC automatic event detection system (M.J. Procopio, C.J. Young and J.A. Gauthier)

DM-08/A: Vertically integrated seismological analysis I: Modeling (N.S. Arora, M.I. Jordan, S. Russell and E.B. Sudderth)

DM-09/A: Vertically integrated seismological analysis II: Inference (N.S. Arora, S. Russell and E.B. Sudderth)

DM-10/A: Can the use of prior information improve signal detection? (N. Selby and D. Bowers)

DM-11/A: Physics-based data mining for seismic bulletins (S.C. Myers and G. Johannesson)

DM-12/A: Exploiting the skills of waveform data analysts in the quest for improved automatic processing (R.G. Pearce et al.)

DM-13/A: Data mining from Antelpe at OGS-CRS (Udine, Italy) (D. Pesaresi et al.)

DM-14/A: How to help seismic analysts to verify the French seismic bulletin? (P. Gaillard et al.)

DM-15/A: Swedish–Finnish Infrasound Network – The research program (L. Liszka)

DM-16/A: Seismic search engine (Yang Liu)

DM-17/A: Ranking methods of classifying radioxenon observations using machine learning for the Comprehensive Nuclear-Test-Ban Treaty (R.K. Ungar et al.)

HYDROACOUSTICS

HYDRO-01/H: Ambient noise (D.L. Bradley)

HYDRO-02/H: Use of CTBTO hydroacoustic resources to investigate global scale ambient noise behavior (D.L. Bradley)

HYDRO-03/H: Hydroacoustic monitoring for CTBTO with a mobile buoy system: Past experiences and new concepts (L. Ginzkey, C. Kubaczyk and J. Ehrlich)

HYDRO-04/H: Results from a 14 month hydroacoustic experiment in the southern Indian Ocean (J.-Y. Royer et al.)

HYDRO-05/H: IMS hydroacoustic phase identification (P. Dysart)

HYDRO-06/H: The role of the IMS hydroacoustic network for characterizing events in the REB (D.C. Jepsen and M.D. Fisk)

HYDRO-07/H: Detection of an in-water event on seismic and hydroacoustic sensors (M.K. Prior, P. Bittner, D. Jepsen, Yan Jia and O. Meless)

HYDRO-08/H: Detection, location, and characterization of hydroacoustic signals using seafloor cable networks offshore Japan (H. Sugioka, K. Suyehiro and M. Shinohara)

HYDRO-09/H: Ocean-acoustic evidence for large conversion of external to internal tide (H. Sugioka, Y. Fukao and T. Hibiya)

HYDRO-10/H: Comparison of CEA hydroacoustic bulletin and IDC hydroacoustic monitoring in the Pacific (O. Hyvernaud)

HYDRO-11/H: Monitoring submarine volcanic eruptions and drifting icebergs in the South Pacific Ocean (O. Hyvernaud)

HYDRO-12/H: Estimating the abundance of blue whales (Balaenoptera musculus) in the northern Indian Ocean using vocalisations recorded by sea-bed mounted hydrophones (D. Harris, L. Thomas, J. Hildebrand, S. Wiggins and J. Harwood)

HYDRO-13/H: Submarine volcanic activity in French Polynesia detected by broadband ocean bottom seismic array (A. Ito et al.)

HYDRO-14/H: The significance of horizontal refraction effect for back-azimuth estimation from the CTBT hydroacoustic stations (Binghui Li and A. Gavrilov)

HYDRO-15/H: Acoustic waves related to tsunami generation (H. Matsumoto and H. Sugioka)

HYDRO-16/H: IMS hydroacoustic contributions to tsunami warning research (D. Salzberg)

HYDRO-17/H: Using IMS hydroacoustic data to monitor whales in the south western Indian Ocean (S. Flore, O. Adam, G. Ruzié, K. Stafford and C. Guinet)

HYDRO-18/H: Deep seafloor arrivals – An unexplained set of arrivals in long-range ocean acoustic propagation (R.A. Stephen et al.)

Appendix 1

POSTERS PRESENTED AT THE ISS CONFERENCE

INFRASOUND

INFRA-01/F:	The IMS infrasound network (P. Campus)
INFRA-02/F:	Infrasound data processing for CTBT verification: station processing (N. Brachet, D. Brown, P. Mialle and R. Le Bras)
INFRA-03/F:	Infrasound data processing for CTBT verification: sources (N. Brachet, D. Brown, P. Mialle and R. Le Bras)
INFRA-04/F:	A robust technique for the automatic detection and location of infrasound events (S.J. Arrowsmith and R.W. Whitaker)
INFRA-05/F:	Towards an automatic and continuous monitoring of the infrasound activity across Europe (L. Ceranna, A. Le Pichon and J. Vergoz)
INFRA-06/F:	An operational approach for infrasound multi-array processing: Application to the Gerdec Albanian explosion (J. Vergoz, A. Le Pichon, D. Green, L. Ceranna and E. Blanc)
INFRA-07/F:	Studies of infrasound event location involving atmospheric events accurately located using dense seismic network data (M. Hedlin et al.)
INFRA-08/F:	Characteristics of seasonally dependent propagation of infrasound wave around the Korean peninsula (Hee-Il Lee, Il-Young Che, Tae-Sung Kim and Jin-Soo Shin)
INFRA-09/F:	Infrasound calibration experiment at Sayarim, Israel (Y. Gitterman et al.)
INFRA-10/F:	Full-wave modeling of infrasound from explosions using the parabolic equation method and realistic atmospheric specifications (R.G. Gibson and D.P. Drob)
INFRA-11/F:	Effects of atmospheric fine-structure on infrasonic signals from explosions (E. Golikova, S. Kulichkov, E. Kremenetskaya, Y. Vinogradov and V. Asming)
INFRA-12/F:	Assessing the detection capability of the global IMS infrasound network (A. Le Pichon, J. Vergoz, E. Blanc, L. Ceranna and L. Evers)
INFRA-13/F:	Estimating the detection capability of the International Monitoring System infrasound network (D. Green and D. Bowers)
INFRA-14/G:	Infrasound detection of rocket launches (B. Gopalaswamy and A. Smirnov)
INFRA-15/G:	Infrasound signals from the test of North Korea's long-range missile (Tae-Sung Kim, Jin-Soo Shin, Il-Young Che and Hee-Il Lee)
INFRA-16/G:	Llaima and Villarrica volcanoes in south-central Chile: An infrasound factory (S. Barrientos, F. Riquelme, N. Brachet, A. Kramer and P. Campus)
INFRA-17/G:	Infrasonic detection of bolides (W.N. Edwards, D.O. ReVelle and P.G. Brown)
INFRA-18/G:	Meteorite detected by infrasound (IS08) and seismic (PS06 and Bolivian network) stations (E. Minaya et al.)
INFRA-19/G:	Seismic and acoustic wave excitations in a single system of the solid Earth and the atmosphere: In the case of the 2008 Iwate-Miyagi Nairiku earthquake (H. Nagao, N. Kobayashi, Y. Fukao, Y. Ishihara and S. Tsuboi)
INFRA-20/G:	Analysis of regional infrasound signals at IS34MN and characterisation of local and regional seismic wave propagation: PS25MN array (Ts. Baasanbat, A. Le Pichon, M. Ulziibat, O. Sebe and Ch. Bayarsaikhan)
INFRA-21/G:	Infrasound monitoring in Kazakhstan: Source localization and characterization (A.A. Smirnov, V.G. Kunakov, A. Le Pichon, J. Guilbert and D. Ponceau)
INFRA-23/G:	Observation and events identification from I33S station (G. Rambolamanana, A. Ramanantsoa, B. Andrianaivoarisoa and F. Randrianarinosy)
INFRA-25/G:	Inversion of infrasound signals for passive atmospheric remote sensing (D. Drob, R. Meier, M. Picone and M. Garcés)
INFRA-26/G:	Gravity waves observed by an experimental infrasound network (J. Marty et al.)
INFRA-27/G:	Study of the dynamics of the atmosphere with the infrasound network (E. Blanc, A. Le Pichon, L. Ceranna and T. Farges)
INFRA-28/G:	The acoustic fingerprint of volcanic ash emission: Results from the International ASHE Project (D. Fee et al.)
INFRA-29/G:	On the monitoring of hurricanes using the international infrasound network (R. Waxler et al.)

ON-SITE INSPECTION

OSI-01/B: Geophysical techniques for on-site inspections – Experience and overview (L.R. Gaya-Piqué and R. Arndt)

OSI-02/B: OSI: A challenging inspection – Logistics for the IFE (J. Anderson and L.R. Gaya-Piqué)

OSI-03/B: The use of aeromagnetic surveys in the framework of CTBTO on-site inspections – Experience from IFE08 (L.R. Gaya-Piqué, A. Grant, M. Purss and G. Tuckwell)

OSI-04/B: IFE08: Integration of on-site inspection elements (E. Jevtic and H. Lampalzer)

OSI-05/B: Seismic aftershock monitoring during an OSI – Experience and results from field exercise in Kazakhstan (P. Labak, M. Villagran and M. Haege)

OSI-06/B: OSI: Measurement of levels of radioactivity (M. Prah and J. Tanaka)

OSI-07/B: Evaluation of on-site inspection activities for planning and implementation (W.L. Hawkins et al.)

OSI-08/B: Enhancing realism of OSI field exercises: Some ideas (J. Sweeney, C. Carrigan, W. Dunlop, S. Luke and A. Dougan)

OSI-09/B: A systems approach to establishing an effective CTBT OSI regime (J. Zucca et al.)

OSI-10/B: Application of a Bayesian approach to search-area reduction during a CTBT on-site inspection (C.R. Carrigan and G. Johannesson)

OSI-11/B: The availability and limitation of OSI technologies (Xiaoyuan Han, Mingyan Jia, Bing Gong, Mei Tian and Hui Xu)

OSI-13/B: Using differential SAR-interferometry for locating ground zero (B. Riechmann, M.B. Kalinowski and J. Schlittenhardt)

OSI-14/B: On-site inspection – A role for satellite imagery (M. Coxhead)

OSI-15/B: InSAR signatures surface expression of natural disasters and human activities (S. Stramondo)

OSI-16.1/B: Geomagnetic observations in Indonesia carried out by BMG (M. Husni, D. Seis and M. Yusuf)

OSI-16.2/B: Geomagnetic observations in Indonesia carried out by BMG: Repeat Station Survey (M. Husni, D. Seis and M. Yusuf)

OSI-17/B: Estimation of ground-level radioisotope distributions for underground nuclear test leakage (J.H. Ely, J.E. Fast, C.E. Seifert and G.A. Warren)

OSI-18/B: Investigations into radionuclide signatures at underground nuclear test sites (J. Friese, R. Payne, R. Arthur and H. Miley)

OSI-19/B: New radionuclide measurement systems improving search and detection capabilities for OSI deployment (T. Köble, W. Rosenstock, W. Berky, H. Friedrich and M. Risse)

OSI-20/B: Investigations into radiological over-flight searches for on-site inspections (C.E. Seifert, J.H. Ely, J.E. Fast and G. Warren)

OSI-21/B: Detection of anomalous gamma-ray spectra for on-site inspection (C.E. Seifert, M.J. Myjak and D.M. Pfund)

OSI-23/B: Aftershock characteristics of explosions relative to earthquake sequences (S.R. Ford, W.R. Walter and J.J. Sweeney)

OSI-24/B: Argon-37 background measurements supporting on-site inspection (C.E. Aalseth et al.)

OSI-25/B: The barometric driven xenon-tracer transport of the Non-Proliferation Experiment simulated by finite volume – Finite element higher-order accurate modeling (R. Annewandter, K. Schmidt, S. Geiger and M. Kalinowski)

OSI-26/B: Detection of trace noble gas emissions from underground nuclear explosions (C.R. Carrigan, J.J. Sweeney and J.J. Zucca)

OSI-27/B: Concept of operations for noble gas on-site inspections (J.I. McIntyre et al.)

OSI-30/B: Dig-into-dust: Resolving ML –2.0 microearthquakes in OSI passive seismics, landslide creep, and sinkhole collapse by nanoseismic monitoring (M. Joswig)

OSI-31/B: Seismic field exercise at AC-IFE08 in Hungary (A.C. Kovács, E.Z. Hegedüs, T. Gûthy and R. Csabafi)

OSI-32/B: Event location through the analysis of seismic waves recorded by mini-arrays in the scenario of an on-site inspection (A. Giuntini, A. Pignatelli, R. Console, S. Chiappini and M. Chiappini)

Appendix 1

POSTERS PRESENTED AT THE ISS CONFERENCE

OSI-33/B:	Passive seismic monitoring of aftershocks during an on-site inspection (A. Smith, A. Spivak, Zhenfu Li and S. Kishkina)
OSI-34/B:	Integrated geophysical investigations under the on-site inspection regime: Detection of cavities in a karst area (M.B.J. Purss et al.)
OSI-35/B:	Software implementations for quality control on seismic surveys: Application to short scale networks. (J. Vila)
OSI-36/B:	Planning an on-site inspection from a potential fields anomaly perspective (A. Pignatelli, I. Nicolosi, R. Carluccio, F. D'Ajello Caracciolo and M. Chiappini)
OSI-38/B:	The limitations of the gravity technique when investigating a possible ground zero (C.J.S. Fourie, R. Murdie and L. Gaya-Piqué)
OSI-39/B:	Short-range and long-range signals of local geomagnetic field variations (F.H. Karimov)
OSI-40/B:	Regional geopotential field effects of underground nuclear explosions (R.R.B. von Frese et al.)

RADIONUCLIDE MONITORING

RN-01/E:	Civil sources of atmospheric radioxenon: Estimating emission strengths (M.B. Kalinowski, M. Tuma and S. Hebel)
RN-02/E:	Measurements of the atmospheric radioxenon background at four locations in Asia and Africa (A. Ringbom et al.)
RN-03/E:	Field measurements around a major European radioxenon release source – a medical isotope production facility (A. Ringbom et al.)
RN-04/E:	Evaluation of environmental radioxenon signals from a singular large source emitter in Africa (P.R.J. Saey et al.)
RN-05/D:	Radon-222 measurements at Cape Point, South Africa (C. Labuschagne, E.-G. Brunke and B.A. Parker)
RN-06/D:	Spurious iodine-131 detections at remote IMS radionuclide stations (K.M. Matthews)
RN-07/D:	The influence on the radioxenon background during the temporary suspension of operations of three major radiopharmaceutical production facilities in the Northern Hemisphere and during the start-up of a radiopharmaceutical production facility in the Southern Hemisphere (P.R.J. Saey et al.)
RN-08.1/D:	Krypton isotopic signature study of the primary coolant of CANDU nuclear power plant (Weihua Zhang, K. Ungar, I. Hoffman and R. Lawrie)
RN-08.2/D:	Noble gas inventories in the primary coolant of nuclear power plant to enhance Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification (Weihua Zhang, K. Ungar, I. Hoffman and R. Lawrie)
RN-09/D:	Ultra-low background measurements of decayed aerosol filters (C. Aalseth et al.)
RN-10/D:	Integration of technologies to aid in search applications for OSI (A.D. Dougan, W.H. Dunlop and B. Adlawan)
RN-11/D:	Development of improved equipment for measurements of xenon radionuclides in atmospheric air (S.A. Pakhomov and Yu.V. Dubasov)
RN-12/D:	Evaluation of cooling technologies for HPGe detectors (J. Forrester et al.)
RN-13/D:	A method for lessening filter clogging on atmospheric aerosol samplers at IMS (L. Liu, H. Tang, Y. Wu et al.)
RN-14/D:	Xenon-133m standard for detection of nuclear weapons tests (K. Peräjärvi et al.)
RN-15/D:	A novel measuring system for detecting and characterizing radioactive particles (J. Turunen, K. Peräjärvi, R. Pöllänen and H. Toivonen)
RN-16/D:	A study on the global detection capability of IMS for all CTBT relevant xenon isotopes (R. D'Amours and A. Ringbom)
RN-17/D:	Global capabilities to detect, locate and characterize radionuclide radioxenon sources and radionuclide particulates advancements in worldwide aerosol particulates monitoring (R.A. Muñoz-Burgos)
RN-19/D:	Characterization of the global distribution of atmospheric radioxenons (A. Ringbom et al.)
RN-20/D:	The operational status of the IMS radionuclide particulate network (R. Werzi)

RN-21/D:	Supporting the CTBT radionuclide monitoring system at the Canadian Meteorological Centre (R. D'Amours, N. Ek, R. Hogue, R. Servranckx and C. Zaganescu)
RN-22/D:	Radioxenon signatures from underground nuclear explosions (L.-E. De Geer)
RN-23/D:	Swedish experience of detecting leakages from foreign underground nuclear explosions (L.-E. De Geer)
RN-24/D:	Discrimination of nuclear explosions against civilian sources based on atmospheric xenon isotopic activity ratios (M.B. Kalinowski et al.)
RN-25/D:	Measurement of Xe-133m/Xe-133 atmospheric isotopic ratio at very low counting level using Bayesian statistical approach (G. Le Petit et al.)
RN-26/D:	Measurements of radioxenon in ground level air in South Korea following the claimed nuclear test in North Korea in 2006 (A. Ringbom et al.)
RN-27/D:	Natural lithospheric radioxenon background in soil gas samples (S. Hebel and M.B. Kalinowski)
RN-28/D:	Detection and activity levels of natural Ar-37 in soil air (R. Riedmann and R. Purtschert)
RN-29/D:	Proficiency test program for CTBT radionuclide laboratories (E.B. Duran, X. Shen, E. McWilliams, L. Cella and R. Werzi)
RN-30/D:	The radionuclide processing system of the CTBTO (M. Nikkinen, M. Zähringer and R. Werzi)
RN-31/D:	IMS radionuclide laboratory GBL#15 (C.L. Comley et al.)

SEISMOLOGY

SEISMO-02/I:	Spot-checking of IMS location accuracy (N.-O. Bergkvist and P. Johansson)
SEISMO-03/I:	Analysis of the location capability of the International Monitoring System (E.A. Bergman and E.R. Engdahl)
SEISMO-05/I:	Multi-reference relocation technique (A. Cichowicz)
SEISMO-06/I:	Consistency of the IDC Reviewed Event Bulletin with other global seismological bulletins and its unique contribution to seismicity studies (F. Kebede and K. Koch)
SEISMO-07/I:	Comparison of IDC and national seismic bulletins in the Italian region (A. Giuntini, R. Console, R. Carluccio and M. Chiappini)
SEISMO-08/J:	Removing periodic noise to detect weak impulse events (J. Altmann and F. Gorschlüter)
SEISMO-09/J:	Analysis of detection capability of the International Monitoring System (E.R. Engdahl and E.A. Bergman)
SEISMO-10/J:	Relative contribution of IMS stations to the Reviewed Event Bulletin of the IDC (J. Coyne, Y. Jia and R. Brogan)
SEISMO-11/J:	Construction and application of time-delay correction surfaces for improved detection and estimation on seismic arrays (S.J. Gibbons, J. Fyen and F. Ringdal)
SEISMO-12/J:	Capabilities of the IMS seismic auxiliary network (D. Hafemeister)
SEISMO-13/J:	Seismic event bulletin evaluation based on probability analysis (Wang Haijun, Liu Junmin and Wang Yan)
SEISMO-14.1/J:	Secondary phase picking and validation (E.S. Husebye, Yu.V. Fedorenko and T. Matveeva)
SEISMO-14.2/J:	Enhanced event locations using Lg-arrivals (E.S. Husebye and T. Matveeva)
SEISMO-15/J:	Analysis of the IDC Reviewed Event Bulletin for detection capability estimation of the IMS primary and auxiliary seismic stations (T. Kværna and F. Ringdal)
SEISMO-16/J:	Enhancements of seismic detection capabilities resulting from the bilateral cooperation of the NDCs of Austria and the Czech Republic (U. Mitterbauer, J. Havír, J. Švancara, P. Melichar and W. Lenhardt)
SEISMO-17/J:	An approach for denoising waveform data by auto-regressive algorithm (N. Arai, T. Murayama, M. Iwakuni and M. Nogami)
SEISMO-19/J:	Local/regional events discrimination using seismic main wavelet and highlight of local conditions using seismic coda (ElHassan Ait ElAasri, Es-Saïd Akhouayri, Driss Agliz and Abderrahmane Atmani)
SEISMO-21/J:	Comprehensive test ban monitoring: Contributions from regional moment tensors to determine source type and depth (M. Hellweg, D. Dreger and B. Romanowicz)

Appendix 1

POSTERS PRESENTED AT THE ISS CONFERENCE

SEISMO-22/J:	Development and testing of seismic regional discriminants (V. Materni, R. Console, S. Chiappini, M. Chiappini and G. Adelfio)
SEISMO-23/J:	Aftershock characteristics of explosions relative to earthquake sequences (S.R. Ford, W.R. Walter and J.J. Sweeney)
SEISMO-24/J:	Satellite earth observations support CTBT monitoring: Case studies including the nuclear test in North Korea of Oct. 9, 2006 and comparison with seismic results (J. Schlittenhardt, M. Canty and I. Grünberg)
SEISMO-25/J:	Difference in seismic cepstrum between explosions and earthquakes (Fu-Sheng Wei and Zhong-Huai Xu)
SEISMO-26/J:	Dealing with hard-to-identify seismic events globally and those near nuclear test sites (L.R. Sykes and M. Nettles)
SEISMO-27/J:	Discrimination of earthquakes and explosions near nuclear test sites using regional high-frequency data (Won-Young Kim, P.G. Richards and L.R. Sykes)
SEISMO-28/K:	On the involvement of the citizens for an improved earthquake response (G. Mazet-Roux, R. Bossu, S. Godey and S. Gilles)
SEISMO-29/K:	The training course "Global Seismological Observation" (T. Hara)
SEISMO-30/K:	On the composition of Earth's short period seismic noise field (K.D. Koper, K. Seats and H.M. Benz)
SEISMO-31/K:	Observations from EarthScope's USArray (B. Woodward et al.)
SEISMO-32/K:	Seismology: Endless frontier (Wu Zhongliang and P. Suhadolc)
SEISMO-33/K:	Recent improvements to earthquake reporting at the USGS National Earthquake Information Center (R. Buland, H. Benz, P. Earle, J. Dewey and W. Leith)
SEISMO-34/K:	CTBTO contributions to tsunami warning (Capacity Building and Training Section, IDC Division, CTBTO Preparatory Commission)
SEISMO-35/K:	A new approach of the rupture process of the great earthquakes using images derived from array processing (J. Guilbert, A. Le Pichon, J. Vergoz and M. Vallée)
SEISMO-36/K:	Continuous seismic scanning in the region of the Mendocino Triple Junction, California (A. Guilhem and D.S. Dreger)
SEISMO-42/K:	Probabilistic estimates of monitoring completeness of seismic networks (D. Schorlemmer)
SEISMO-43/K:	Seismological approach to earthquake forecast in western Nepal Himalaya and its adjoining Indian region (D. Shanker, H. Paudya and H.N. Singh)
SEISMO-44/K:	Proposal on the organization of complex monitoring of nuclear explosions in Armenia (H. Babayan)
SEISMO-45/K:	Efficient and accurate calculation of ray theory seismic travel time through variable resolution 3D earth models (S. Ballard, J.R. Hipp and C.J. Young)
SEISMO-46/K:	Crustal investigations of northern Iraq from seismic studies (R. Gritto et al.)
SEISMO-47/K:	Large-scale array use for phase identification and waveform determination (G. Helffrich and J. Wookey)
SEISMO-49/K:	1-D shear wave velocity structure of North Korea (Tae-Sung Kim, Ik-Bum Kang, Geun-Young Kim, Jin-Soo Shin and Heon-Cheol Chi)
SEISMO-50/K:	Using IMS seismic arrays to constrain the structure of Earth's deep interior (K.D. Koper and Yan Xu)
SEISMO-52/K:	Joint inversion of surface wave velocity and gravity observations and its application to Central Asian basins shear velocity structures (M. Maceira and C.J. Ammon)
SEISMO-53/K:	A model and methods for the computation of regional seismic travel times (S.C. Myers et al.)
SEISMO-54/K:	Testing the global capabilities of the Antelope software suite: Fast location and Mb determination of teleseismic events using the ASAIN and GSN seismic networks (D. Pesaresi, M. Russi, M. Plasencia and C. Cravos)
SEISMO-55/K:	Upper mantle elastic structure inferred using the spectral element method (V. Lekic and B. Romanowicz)
SEISMO-56/K:	Open data exchange in support of CTBT research (D. Simpson and R. Willemann)
SEISMO-59/K:	A review of seismological studies in Bangladesh (T.M. Al-Hussaini)
SEISMO-61/K:	Large and great earthquakes in the stable continental region of India: Seismotectonic perspective (J.R. Kayal)
SEISMO-62/K:	Muzaffarabad earthquake of October 8, 2005: Source parameters using empirical Green's function technique (M. Tahir et al.)

SEISMO-63/K: Focal mechanism solution of the 15th March 2008, Nyamandlovu earthquake (B.T. Shumba, D.J. Hlatywayo and V. Midzi)

SEISMO-64/K: Results from IMS seismic array in Niger (C. Estabrook, B. Bergsson, S. Soumana, O. Boureima and M. Moumouni)

SEISMO-65/K: CTBT space-based monitoring: Interferometric synthetic aperture radar and national technical means (D. Hafemeister)

SEISMO-66/K: The DPRK event of May 25, 2009: A preliminary analysis carried out at INGV from a multidisciplinary perspective (M. Chiappini et al.)

SYSTEM PERFORMANCE

SP-01/C: Global environmental problems: Negotiating international integrity of goals (T. Ermolieva, Yu. Ermoliev, G. Fischer, M. Jonas and M. Makowski)

SP-02/C: Analysis of system performance applied to the territory of Romania (2004-2008) (D. Ghica, M. Popa and V. Oancea)

SP-03/C: Seismic monitoring – problems (H.R. Malephane)

SP-04/C: Simulations of IMS detection effectiveness as deployed vs planned (J. Arzigian and J. Damico)

SP-05/C: NDC Preparedness Exercises: Performance assessment of the CTBT verification system by simulating realistic scenarios (N. Gestermann and M. Henger)

SP-06/C: Is there an identifiable human signature in the International Data Centre products? (D. Steinberg and Y. Ben-Horin)

SP-07/C: Advances in data integration and quality control in support of ground-based nuclear detonation detection (R.J. Stead, M.L. Begnaud and J.C. Aguilar-Chang)

SP-08/C: Bridging the missing link to strengthen CTBT verification regime (I. Tumwikirize)

SP-09/C: Overview of standards activities in reliability and QoS for CTBTO's evolving Global Communi-cations Infrastructure (S.E. Makris and P. Tarapore)

SP-10/C: Towards a reliable communication network for International Monitoring System (S.K. Chandran and S. P. Mälardalen)

SP-11/C: Verifying timing quality of seismological stations using teleseismic arrivals (K. Stammler)

SP-12/C: SEL1 vs REB bulletins comparison: Looking for underlying features (R. Carluccio, R. Console, S. Chiappini and M. Chiappini)

SP-13/C: Towards a portable rule-based agent for monitoring the data of the International Monitoring System (IMS) (A.I. El-Desouky, H.A. Ali and S. Laban)

SP-14/C: On the reliability of the CTBT International Monitoring System (R.A. Gustafson)

SP-15/C: Physical modeling as quality control tool for calibration, instrument responses and orientation (R. Le Bras, M. Malakhova, J. Given and J. Stevens)

SP-17/C: Civil society's contributions to CTBT verification (A. Falter, D. Deiseroth and M.B. Kalinowski)

SP-18/B: Promoting use of IMS data and IDC products through capacity building initiatives (Capacity Building and Training Section, IDC Division, CTBTO Preparatory Commission)

SP-19/B: Performance monitoring and assessment by the PTS (S. Alamo et al.)

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